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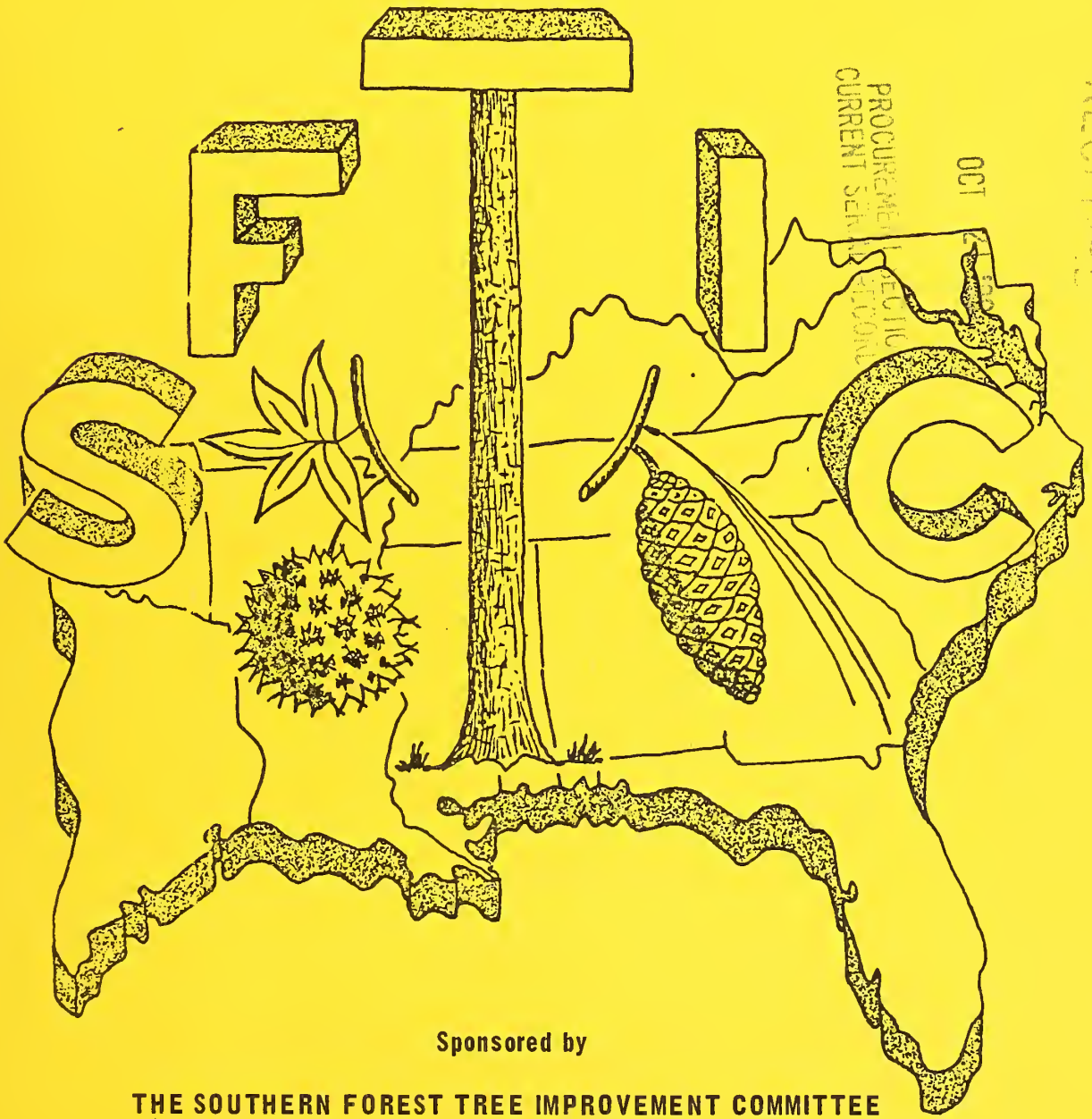
13TH SOUTHERN FOREST TREE IMPROVEMENT CONFERENCE



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JUNE 10 & 11, 1975

RALEIGH, NORTH CAROLINA

PROCEEDINGS OF THE

Thirteenth Southern Forest Tree Improvement Conference

Raleigh, North Carolina June 10-11, 1975

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SOUTHERN FOREST TREE IMPROVEMENT COMMITTEE

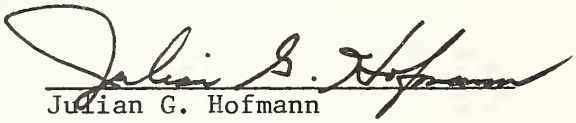
FORWORD

The Thirteenth Southern Forest Tree Improvement Conference is now history. In spite of economic restrictions by many companies and government agencies, more than 170 paid attendees participated. The arrangements and smooth operation would never have been possible without the dedication and hard work of my Conference Co-Chairman Dr. Ellis Cowling. His meticulous attention to detail made the Conference a huge success. He was ably assisted by the Department of Continuing Education in providing assistance in registration, coffee breaks and all the sundry housekeeping chores without which such an endeavor cannot succeed.

As instructed by the Committee last year, I now thank both Conference Co-Chairmen. Amen. We could not have functioned without the advice and counsel of Dr. Bruce Zobel.

This year's meeting spawned nearly a dozen meetings held at various times before, during and after the Conference. This exchange of ideas in many allied fields can do nothing but help in solving problems within the many disciplines represented at this southwide Conference.

I hope that the Fourteenth Conference scheduled in 1977 at Gainesville, Florida will be large and as successful as this one. To all the speakers, moderators and attendees, I wish to say thanks. We in the North Carolina operating area are mighty pleased you stopped by.



Julian G. Hofmann
Chairman, Southern Forest
Tree Improvement Committee

June 20, 1975
Roanoke Rapids, North Carolina

Purpose of the Southern Forest Tree Improvement Conferences

The purpose of the Southern Forest Tree Improvement Conferences is to stimulate exchange of ideas and current research findings, and to encourage informal communication about the genetic improvement of forest trees. Participants include government-, university-, and industrial research scientists, graduate students, industrial foresters, state and federal forest land managers, and others who share an interest in developing trees of superior form, rate of growth, wood and fiber quality, and resistance to diseases, insects and unfavorable environmental influences. These conferences are held every other year at various locations throughout the southern United States. They are sponsored by the Southern Forest Tree Improvement Committee whose general purposes are:

1. To advise and assist those interested in the improvement of southern forest trees in arranging and conducting research and development programs.

2. To provide a clearinghouse for information on forest tree improvement.

3. To provide for or assist in coordination in the conduct of a southwide program of tree improvement research and development.

4. To foster and encourage the advancement of knowledge of southern tree genetics.

The Thirteenth Southern Forest Tree Improvement Conference was held in Poe Hall on the campus of North Carolina State University in cooperation with:

The School of Forest Resources North Carolina State University Raleigh, North Carolina 27607	and the	Division of Continuing Education North Carolina State University Raleigh, North Carolina 27607

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SESSION I - ECONOMICS

MODERATOR: BRUCE J. ZOBEL

PINE TREE IMPROVEMENT TO DATE AND TOMORROW

William T. Gladstone[1]

Abstract. Within the framework of broad-based recurrent selection programs, fine-tuning of genotype-site relationships will maximize genetic gains. Straightness and form characteristics will assume greater importance as log diameters diminish. Vegetative propagation will become operational and forestry operations will become more labor intensive. The nature of forestry, with its basic assets, the soil and the tree, provides an unparalleled opportunity for its practitioners to develop the code of personal ethics necessary for survival in the future.

"The fit are those who fit their existing environment and whose descendants will fit future environments."

Thoday (1958)

TO DATE

Where is southern pine tree improvement today? For details, I'll refer you to the North Carolina State Cooperative's 19th Annual Report (1975). The generalities are as follows:

- We're in an embryonic state of development when compared with genetic and cultural programs of other plants and animals, however we can profit and will profit by the mistakes and success of these other programs.

- Natural genetic variability at three major levels is being utilized to provide the best planting stock available for regenerating harvested acres. For a given region or broad management area:

  A. The proper species is selected.

  B. The best source(s) within that species is selected. We lean heavily on local material where seed orchards are involved, but are rapidly researching the movement of material.

  C. The best individuals within sources are being used as seed orchard parents. Through seed orchards we concentrate and perpetuate populations

[1]Manager, Southern Forestry Research Center, Weyerhaeuser Company, Hot Springs, Arkansas

of good genotypes.

What are "best individuals"? The major goal of pine improvement, and thereby the ultimate selection or fitness characteristic, combining all others, is the maximum production of wood in some specified form and/or with some specified properties. Any selection criterion which can contribute to production directly or indirectly, independently or in concert with other criteria can be useful. Volume growth, disease resistance, and straightness are examples of obvious and very important traits.

The most visible tree improvement activity occurs at the individual selection, or seed orchard level, where we are, for the most part, breeding broad-based populations which are regionally specific. First generation orchards represent somewhat narrower geographic ranges than do 1½ and second generation orchards, since the latter contain the best clonal material available from regional cooperators. Volume gains of 20% and 35%, respectively, are anticipated from 1½ and second generation orchards, dramatic contributions to the South's Third Forest.

The seedlings produced from the output of the orchards are being planted on relatively diverse sites and microsites, the broad genetic base of the bulked material insuring improved performance but perhaps not optimum attainable performance. The question arises....."How site specific can we afford to be?". Genotype-site interactions apparent in progeny test results suggest that there are growth gains to be made by matching families and sites. How closely can or should we machine that fit? Specialty orchards have been established, concentrating on disease resistance, adverse site conditions, and wood properties. I foresee more effort devoted to specialty orchards.

Insofar as operational planting is concerned, we are not yet able to cash in on those extra-good specific combinations (full-sib families) which have been identified in progeny tests. Two clone orchards are coming in and mass pollination techniques will be developed to increase the production of excellent crosses. Vegetative propagation of individual genotypes for operational planting would provide the means for testing and using that apparently rust resistant individual from a very susceptible family or those gun-barrel-straight individuals from families which are already represented in the next generation's orchard by other family members.

Despite my inclination toward site-genotype specificity, I recognize the need for inter-company and inter-regional crossing. By planning and implementing these programs now, we're insuring that the descendants of our current pine populations will be able to fit future environments. We face the universal breeding dilemma -- long range needs for adaptability to diverse and changing environments versus short term desires for specificity and maximum immediate gains.

Is it conceivable, however, that by working diligently with first, 1½, and second generation material, carefully matching genotype to site and product needs by such methods as

. Segregating and planting half-sib families,

. Producing and segregating full-sib families, and

. Operationally propagating selected individuals

that overall gains could be equivalent to the gains achieved by the broad-based approach to the third generation? (Unsafe levels of genetic homogeneity would be avoided.)

I can't answer that question unequivocally. But while I certainly advocate that we produce our third and fourth generations as rapidly as possible, the long range spectre of limitations on the amounts of suitable breeding material suggest that a more intensive examination and utilization of what we have at hand is in order. At this point we run up against economics. Most organizations haven't the resources to manage tree improvement this intensively.

That's generally where we stand today, with a few thoughts on where some emphasis should be added in the near future.

TOMORROW

A Broad Perspective

What does the distant future look like? Let's examine it on a broad scale and then return to the forest and to pine tree improvement.

If you've been reading *The Limits to Growth* (Meadows, et al. 1972), *Mankind at the Turning Point* (Mesarovic and Pestel 1974), or *How to Get to the Future Before it Gets to You* (Mead 1974), then you're probably as confused as I am about the prospects for solving our national and international problems. Is technology the answer? Or should our by-word be "Natural is Beautiful"?

William W. Harman of the Stanford Research Institute (Critical choices as the United States enters its third century-1973 mimeo) states that the dilemmas of the whole industrialized world appear to be unresolvable in any satisfactory way. "The basic tradeoffs between environment, life styles, personal freedoms, amenities, international stability, high energy cost and high cost of goods, public health, unemployment and economic recession, and other social costs, are growing more intolerable and it is not clear what could be done to make them less so." Life styles, international stability, high energy cost, unemployment, economic recession are particularly critical right now. We have entered the inevitable era of scarcity ahead of schedule; inevitable because of the finiteness of non-renewable resources, and ahead of schedule because of impending worldwide redistribution of resources and wealth. Witness the oil and bauxite cartels and expect others.

My own inclination is to be moderately pessimistic about our material standard of living but optimistic about other less tangible but important qualities of life. I think that Dennis Meadows' (co-author of *The Limits to Growth*) comments in *Business Week*, May 12, 1975, are not far wide of the mark:

"We will not be able to provide the same flow of materials and energy through the households of America in 10 to 15 years as we can today. The material standard of living will have declined sufficiently by the end of the 1980's to pull the rug out from under a lot of mass consumer markets. I think it is likely that the U.S. economy is going to deteriorate very seriously." I'm not so sure of the time scale, but I think that the trend is already becoming apparent.

This assumes, of course, that we and other developed nations do not indulge in wars of 'preemptive seizure', a morally bankrupt policy of taking what we want if we can get it militarily.

According to the authors of *Mankind At The Turning Point* (Mesarovic and Pestel 1974), an individual's new code of ethics must include:

- A world consciousness and a sense of common human destiny.
- A harmonious attitude toward nature.
- A life style compatible with limited resources. This requires a new technology of production based on minimal use of resources rather than maximal throughput.
- A sense of identification with future generations. We should be ready to relinquish benefits for ourselves in favor of future generations. (Are we "fit"?)

Idealistic, perhaps, and not in accord with economic precedents, but the problems which we must solve are also unprecedented.

A Forestry Perspective

All of this suggests to me that industrial and public forestry operations should and probably will become more labor intensive. The idle hands will become available; the challenge will lie in assuring those hands a sense of dignity, accomplishment, and satisfaction.

Aside from reserving energy and capital equipment resources for manufacturing operations, many silvicultural benefits from labor intensive management can be enumerated. Foremost would be the establishment of relatively small management blocks with permanent working forces which have a commitment to the land, a personal identification with the complete forest. Minimize contractual, absentee operator arrangements and thus minimize the "I don't care what happens after my phase of the operation is over" attitude. The harvester becomes the planter, the weeder, the thinner, the pruner, and finally, the harvester again.

Decrease the mobility of the professionals involved so that they can acquire an intimate knowledge of their particular soils, their plant material, and the subtle and not-so-subtle interactions between the two. A more favorable balance of mechanical and selective thinning will be achievable with a larger labor force and should result in a better disposition of individual phenotypes in a given plantation. It'll still be a clear-cut and plant proposition, however the cutting and regeneration units can be better regulated to the advantage of

environmental concerns. Harvesting and site prep machines which are absolutely indispensable should be precisely scaled to fit their jobs.

One of my major concerns, based on the forecast that energy will become a scarce, more expensive commodity, is that it will be desirable, if not mandatory, to minimize the amount of reconstitution necessary to fully utilize the wood available to us; i.e., the value of solid wood products relative to that of reconstituted products will increase in the future. Short rotation plantations mean diminishing log diameters and consequently lower yields, per cubic foot of raw material, of sawn products and veneers. It is important to note that losses of yield due to sweep and taper are proportionally greater as log diameter decreases.

Questions dealing with planting densities, thinning regimes, rotation ages, diameter distributions, and log quality come up daily in the South, but, critical as they are, I'm afraid we procrastinate in dealing with them. Our efforts to maximize cubic volume or weight per acre per year will have the effect of pushing the fractionation of our raw material back into the woods and materially increasing the necessity of gluing it back together. As an industry, we foresters are fortunate that one of our basic resources is a solar energy converter. Solar energy puts wood together.....we should leave as much of it intact as possible. Creating specific surface, mechanically or chemically, consumes energy. Even companies which traditionally have been totally fiber oriented may find it profitable to recover solid wood products.

A Tree Improvement Perspective

What implications do labor intensive management and pressures for small log quality have for tree improvement?

Increased emphasis on form and straightness. Vegetative propagation in some form will permit the replication of near-perfect genotypes. This may be the primary contribution of tissue culture to pine forestry. Regular distribution of stems in properly planted, well stocked plantations should help to minimize sweep and eccentricity caused by unbalanced competition. Thinning and control of non-crop vegetation will have to be executed with care to preserve the competitive balance of a plantation.

Custom matching of species, provenances, families, and individuals to site conditions. Our ability to do this will be greatly improved by continued trial and observation by permanent field personnel. Single family plantations of limited size will permit close matching. Furthermore, recognizing that there is considerable between family variability in straightness and branching characteristics, some attractive management alternatives may be available at harvest, these same alternatives being lost if families are bulked. Somewhat longer rotations for straight, small-limbed families may be justified by the prospect of increasing grade volume (maximizing value increment), for example, while rougher families are harvested on the basis of mean annual volume increment, and wind up contributing heavily to chip supplies. I should include here an intensification of breeding for marginal sites. Agriculture will be competing for our most productive sites.

Orchards and nurseries will become more labor intensive. Mass, or controlled, pollination will be more manageable with more people and will make orchard design more flexible. Specific combining ability will be utilized to a greater extent. Good selections which are out of phase phenologically can be useful if artificially pollinated, adding to our genetic base. Harvesting, extraction, and stratification of seeds will be customized by family, as will nursery culture.

Intensification of breeding for resistance to or tolerance of disease and insects. The objectives, of course, are to improve plant efficiency, however reducing pesticide-energy requirements and minimize environmental impacts are side-benefits.

Creation and testing of new variants. Accelerated selection and breeding programs will reduce the generation lag, expediting the appearance of more efficient trees. Inter- and intra-specific hybridization, and mutagenesis (including chemical, radiation and nuclear fusion) will provide new genotypes.

Continued efforts. Cone and seed insect research, orchard cultural treatments, containerized breeding orchards, frost damage control, and a myriad of other research and development activities will continue to improve our efficiency and lower our costs and losses.

SUMMARY

Within the framework of broad-based, recurrent selection programs, fine tuning of genotype-site relationships and genotype product relationships will maximize genetic gains. Straightness and form characteristics will assume even greater importance as log diameters continue to diminish. Both genetic and intensive environmental controls will be brought to bear on log quality.

Vegetative propagation in some form will permit us to replicate excellent genotypes on an operational scale and thus take advantage of very specific gene combinations.

At some point in time forestry operations in the orchards, the nurseries, and the field will become more labor intensive, providing the manpower needed to accomplish a general increase in management intensity.

The nature of forestry, with its basic soil asset and its renewable asset, the tree, provides an unequalled opportunity for its practitioners to develop the code of personal ethics which will be necessary for survival in the future. Our pines may be "fit", but are we?

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HARDWOOD TREE IMPROVEMENT TO DATE AND TOMORROW

J. S. McKnight 1/

Abstract.--Sycamore, sweetgum, black walnut, cottonwood, yellow-poplar and eucalyptus have been planted in commercial size plantations in the Southern U.S. These species and 35 more are under some degree of tree improvement research with very small seed orchards established for 15 species. Limited research funds dictate a challenge to systematically analyze for prediction of future tree improvement needs with selected hardwood species. Twenty-nine institutions are doing some study of tree improvement research with hardwoods.

Additional keywords: Genetics, planting, superior tree selection.

Tree improvement in hardwoods has been a haphazard thing, a searching for meaning and direction. Reason is gradually bringing some semblance of order as sufficient experience is generated among researchers and as economic and aesthetic demands unravel themselves. About 40 hardwoods have been touched by the magic wand of experimental endeavor in the U.S. but only a few species are on the way to practical improvement (Table 1). Thus, with limited funds and personnel, research organizations have been working on a broad front. Now it appears time for an assessment of where that exploring has brought us and to once again reason together for a more meaningful effort into hardwood tree improvement.

Table 1.-- Listing of hardwood species on which there has been some tree improvement research

Eastern cottonwood	Cherrybark oak	Black alder
Black cottonwood	Black oak	Hackberry (sugarberry)
Plains cottonwood	Scarlet oak	Balsam poplar
Yellow-poplar	Swamp chestnut oak	Aspen
Black walnut	American chestnut	Basswood
Black cherry	Chinese chestnut	American elm
Sycamore	White ash	Water tupelo
Sweetgum	Sugar maple	Black tupelo
Green ash	Silver maple	Swamp blackgum
Northern red oak	Red maple	Royal paulowonia
Southern red oak	Pecan	Ailanthus altissima
Chestnut oak	Black birch	Eucalyptus spp.
White oak	Yellow birch	Eurasian elms
Water oak	Paper birch	Persian walnut
Willow oak	River birch	English oaks

1/ Consulting Forester, Stone Mountain, Georgia

COMMERCIALLY PLANTED SPECIES

Cottonwood

The hybrid poplar program started by Ernest Schreiner in 1925 in the northeast is still alive and well. A survey by the Northeastern Forest Experiment Station of public and private nurseries during the spring of 1974 showed between 4 and 6 million trees were out-planted either as rooted or unrooted stock. The plantings are scattered on small areas and spoil banks associated with mining.

In the South, genetically improved Stoneville select cottonwood clones are being planted on a large scale (Mohn, 1970). Some wood industries have selected and planted clones of eastern cottonwood which exhibit at least juvenile superiority. Between 40 and 50,000 acres of cottonwood are now in commercial plantations and the majority of new plantings are of superior clones. Of equal or even greater importance to the success of this first major commercial planting of hardwoods in the U.S. were the intensive methods of site preparation, planting and tending of the trees found essential to the over-all tree improvement program (McKnight, 1970). Lessons learned by researchers and practitioners with this species have guided tree planters in developing methods for successfully planting other species of hardwoods on a commercial scale.

Black Walnut

Some basic genetic trends for this species have been established and forest geneticists are talking about improved seed to produce better timber trees in the future. A total of 181 acres of walnut seed orchards were reported in October of 1974 for the eastern United States, the greatest number of acres for any hardwood (Table 2). The multiple objective seed orchard is being used for black walnut because of the value of nuts and lumber. Hundreds of clones are being tested at a number of locations in the East and Midwest. Plantation care has been found basic to establishment of successful walnuts as it has with other species. Both chemicals and mechanical cultivation have proven successful, each for the particular circumstances under which walnut has been planted.

Sycamore

The planting of sycamore has run the experimental gamut from the silage concept (McAlpine 1966) to conventional planting supplemented by intensive care in planting and cultivating during establishment years. Thousands of acres are now planted to this species and research and application trials have guided successes (Briscoe 1969). Recent research with this species at Stoneville, Mississippi, has shown that southern sources grow faster and are more disease resistant (Ferguson, etal and Cooper etal, in press). When this information is put to use, much better and faster growing sycamore should be the result in commercial plantations.

Sweetgum

This tree may be the most important species of hardwood in the South due to its relative freedom from insects and diseases, the desirability of the wood for many uses, and its apparent ease of propagation with prolific seeding annually, beginning within the first five years after planting. Early emphasis on tree improvement was of variability in natural stands and on progeny testing to obtain measures of phenotypic, genetic and environmental variances, genotype environmental

interactions, heritabilities, correlations, and effectiveness of selection in natural stands. Large differences in foliation dates have applicability. Progeny that foliate early have been found to be the best growers on sites and soils where moisture supply is depleted early in the summer. However, tests so far show selection in natural stands has been ineffective in improving growth of progeny. Although thousands of acres of this species are planted, every plantation where there is a high degree of success has shown poor height growth in the first several years but has grown rapidly thereafter. One plantation averages 7"d.b.h. at age ten, where it was cultivated to keep down weeds during establishment.

Progeny or provenance experiments are being conducted by the Western Gulf Regional Tree Improvement Cooperative, North Carolina State University Industry Cooperative Tree Improvement and Hardwood Research Program, International Paper Company, and the Southern Forest Experiment Station.

Table 2.--Summary of acres of hardwood seed orchards, by species and region 1/

Species	South 2/ (Acres)	West and North (Acres)	Total
Northern red oak	51	26	77
Sycamore	5		5
Black cherry	2	48	50
White oak	2		2
Hybrid poplars	6		6
Cottonwood 3/	1	3	4
Chinese chestnut	4	2	6
Black walnut	49	132	181
Sweetgum	15		15
Yellow-poplar	40	10	50
Maple	4		4
Cherrybark oak	2		2
American chestnut	1	2	3
Persian walnut		5	5
Paper birch		5	5
	182	233	415

1/ Summarized from U.S. Department of Agriculture, Forest Service. Forest Tree Seed Orchards, A Directory of Industry, State and Federal Forest Tree Seed Orchards in the U.S. 33 pp. October, 1974.

2/ Includes Mo. and Ktky.

3/ This figure does not show the several hundred acres used for vegetative propagation of superior cottonwood clones for planting in the Mississippi Valley.

Yellow-poplar

This species is one of the most widely planted hardwoods in the Southeast even though plantations in any one place are limited in size. There are over 50 acres currently in seed orchards and research in superior tree selection and progeny testing is underway in a number of locations. Although a fast-growing tree its wood characteristics do not make it very desirable for pulpwood, it is a favorite species for furniture plywood core stock.

Eucalyptus

Eucalyptus was first planted in Southern Florida before 1900 where it was used for a shadetree. Eucalyptus robusta, after intensive research for genetic improvement begun in 1966 (Franklin etal 1973), is now being used to establish commercial plantations for pulpwood production in the warm climes. Additional research is underway at Bainbridge, Georgia where frost-hardy species of eucalyptus are being sought for planting on sites typically dry in summer months.

GUIDES TO FUTURE TREE IMPROVEMENT

There you have it, a too-brief summary of where we are in the application of hardwood tree improvement, but essential to a review of where we are going. Research on over 40 species is underway; yet, only sweetgum is a species that can be widely planted on a range of sites. Sycamore, cottonwood and black walnut, though aimed at entirely different final products, are all prima donnas that need careful site selection and intensive care for establishment. Eucalyptus is limited by climate to areas of frost-freedom. Yellow-poplar is primarily a factory lumber or commercial veneer species.

Many other species have peculiar properties that make them desirable trees in specific situations and/or specific for specific products. For example, green ash is an easy one to grow in the nursery, plants well, and is successful on many wet, clay sites. Its wood is desirable for fiber and for many solid products of high value. The oaks are tremendously variable in growth rates between species but all have high specific gravity and produce good yields on a wide variety of sites. However, some of the easiest to propagate, such as pin oak and water oak, rarely develop clean stems suitable to high quality lumber production. No one has come out with a sure-fire way to kick off early growth of oak, though several researchers are delving deeply into studies on the subject. Water tupelo grows well in nurseries and can be planted successfully in swamps.

Lest we forget, not all tree improvement aimed at increased timber production yields superior planting stock for that purpose alone or even for that purpose at all. For example, cottonwood selection yielded some progeny that were persistently limby to the ground -- good characteristic for windbreaks but not so good for timber. Sweetgum progeny tests discovered vivid colorations in spring and fall foliage in some trees -- desirable for roadside and urban plantings.

Although we see the beauty of cherry probably more than any other wooden furniture part, the research in black cherry improvement is limited. Various reasons are given including the ease of propagating this species naturally. Still, in relation to black walnut the effort in tree improvemnt for this fine furniture wood is mighty slim when you consider that the species is adaptable to a broader range of sites than black walnut.

In my estimation some approach similar to that discussed by Farmer (1973), for administrative decision-making will need to be used at all levels to stretch the research dollar and to eventually yield the most useful results. Specific industry programs might take a different evaluation than one made for the non-industry private sector. However, in both cases planting to translate genetic improvement to application will need to be feasible and thoroughly tested to assure biological and financial success. "Tree improvement" becomes the whole program, including genetically developed superiority and the range of other inputs such as planting methods to insure cost efficiency. With thirty research institutions doing some form of tree improvement on a wide range of species, such a system is mandatory (Table 3).

The method of ranking used by Farmer integrates available quantitative information and judgment of experienced specialists around key elements of species selection. Weighting and scoring provide a ranking of species. The inputs include (1) value improvement rate; (2) predominance in existing forest; (3) values for uses other than timber production; (4) plantability; (5) acreage available for artificial regeneration; (6) likelihood and cost of breeding success; (7) and cost of improved stock.

Marquis (1973) points out the variation in potential returns from hardwood tree improvement. He states that black cherry and paper birch could sustain much higher expenditures for some genetic gain than could red oak. Species that produce large quantities of seed and species with high sawtimber values and rapid growth rates are likely to be good tree-improvement investments. I would add that where there are ready or developing markets for hardwood fiber, the investment-time factor before financial return must strongly enter the picture. Of major importance is his conclusion that the amount of genetic gain required to justify tree improvement for the fine hardwoods is small. He calculates that increases in quality, or growth increases in excess of 10 percent, would make for profitable investments with this species.

Dutrow, etal (1970) provide an investment guide to cottonwood planters and indicate a 20 percent increase in yield from superior cuttings. Of particular importance to the cottonwood investor and tree improver are the figures allowing determination of returns to be expected for pulpwood rotations alone and a combination of pulpwood-sawtimber-veneer timber rotations at various initial establishment costs. Such investment guides should be an aid to the researcher who must analyze opportunities before investing years and dollars into genetic improvement research.

OTHER CONSIDERATIONS

There is often a tendency to plod the same paths though change may indicate a better direction. Selection of species to apply the approach of total tree improvement might be guided by the so-called multiple use concept. Trees in forests, whether naturally occurring or planted, can provide timber, wildlife food, aesthetic buffers, windbreaks, water filters, soil binders, and so on. Perhaps we should all be considering some new approaches, or maybe not-so-new but, at least, little talked about. For example, in cottonwood plantations for sawtimber, interplanting with superior pecans may provide particular mast for wildlife, excellent timber, and a variety in the forest.

As we look to genetic improvement of sweetgum and maples, there will be foliage of some progeny extremely pleasing for fall colors. Perhaps some attention to

Table 3.--Some institutions doing tree improvement relative to concerns of the Southern Forest Tree Improvement Conference.

Institution	Oak	YP	Cw	Syc	Sg	Chs	Map	Elm	Pec	EO	Wal	Tup	BC	Bir	Ash	Bass	Ail	BLoc
Forest Ser.																		
SO	*	*	*	*	*				*		*	*			*			
SE	*	*		*	*					*		*	*					
NE	*		*				*	*					*	*	*			
NC	*		*				*				*							
NCSU Coop.	*	*		*	*		*				*	*	*		*	*		
TVA	*	*									*							
VPI	*																*	
U.of Ga.	*	*		*	*													
Auburn				*	*													
Miss.St.U.					*										*			
LSU			*	*					*									
Tex.A&M Coop.	*		*	*	*										*			
Okla.St.U.			*															
U. of Tenn.	*	*				*					*							
U. of Ktky.	*	*		*							*							
Clemson U.	*	*			*													
Sou.Ill.U.											*				*			
U. of Ill.			*					*										
Purdue								*			*							
Ia.St.U.								*			*							
Kan.St.U.	*		*				*		*		*							
Mich.St.U.	*																	
U.of Minn.				*				*										
U. of Neb.				*														
Ohio Res.Ctr.	*	*	*															
St.F.Austin				*										*				
West Va. U.	*	*						*			*		*					*
U. of Wisc.								*			*							

planting these varieties along roadsides and interspersed on appropriate sites with pine could reduce the accusing "monoculture" designation being assigned commercial plantations of a single species.

In mountain hardwoods regeneration with improved stock may well take the form of a few dozen crop trees per acre, cared for individually, rather than the present row-planting. Underplanting or interplanting has been found feasible with birch, maple and some oaks. Though this method may not be suitable for lowland sites and for large industry-oriented holdings it may be the most feasible approach on upland sites of relatively small acreage held by non-industrial owners. Minkler (1975) suggests a form of silviculture for multiple benefits to such owners where the crop tree approach to incorporating genetically improved stock may be entirely acceptable.

Some bottom-land sites in the South are typically a series of ridges, flats sloughs, and swamps. Some very wet areas during normal planting season have excellent soils that don't come out from under water until the seed have all gone. Here underplanting of green ash that has been selected for good initial growth in partial shade may put low-productive forest conditions into high production with relatively little cost for site preparation and cultivation. Once the trees are well established the unwanted overstory can be removed, if merchantable, or deadened if cull. Similarly, work with tupelos already started by the Forest Service at Charleston and Stoneville should concentrate on tree improvement, in its broadest sense, to provide planting stock and methods suited to planting in the fall when water levels are low in swamps.

There are hundreds of thousands of acres of sites where clays predominate in soils that drain slowly on the outside and little at all internally. In some cases the very best trees on such sites would be those that quickly produce wood of high yield but perhaps of less than desired clearness for factory lumber or veneer. The full range of planting recommendations will compose "tree improvement" for such sites and the part of genetic improvement may be to provide an oak or an ash or whatever that is plantable at other times than winter or early spring, has good initial growth, and sustains acceptable growth until minimum size for harvest. At the same time the species chosen might well be a mast producer to enhance the value of the forest for wildlife.

A NEW CHALLENGE

From this analysis can be drawn six recommendations:

1. Systematically analyze for prediction of future needs. Eliminate research on species or site-species combinations that do not stand up to par on objective analysis.

2. Do not overlook the trend toward forest practices that demand a forest with variety to meet many human needs.

3. Do recognize the potential productivity of some difficult to plant sites, both natural, such as swamps, and artifically created, such as strip mined areas.

4. Do consider total "tree improvement" and plan genetic improvement around the many facets of planting or seeding a particular species or variety for a specific site and forest condition.

5. For the big planting opportunities look to the "tough" species or strains that seem to grow under a variety of conditions and are used for a number of purposes. Assess potential for developing planting stock relatively free of disease and insect pests.

6. Continue and expand basic research that answers questions about "how trees make wood?" Information gained by such research will further refine the decision-making process recommended in the first challenge.

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MEASURING GENETIC GAINS BY PROJECTED INCREASES IN FINANCIAL RETURNS

Clark Row and George Dutrow[1/]

Abstract.--A new approach to projecting economic gains from genetically selected forest trees estimated increases in revenues from loblolly pine that ranged up to 150 percent or $20 per acre per year. The method combines data from genetic trials with mathematical growth models that project specific stand characteristics. Product value functions use these characteristics to determine value gains at harvest. The approach shows promise of becoming a valuable tool for evaluating genetic crosses, and for assessing impacts of genetically improved stock on management programs.

Additional keywords: Loblolly pine, Pinus taeda, height growth, diameter growth, survival, genetic selection.

In forest genetics programs, one ultimate measure of gain is the increase in revenues from commercial plantations of improved trees. In each step of tree improvement programs, starting with selections from wild populations, geneticists must place either explicit or implied values on inheritable characteristics. The development of an improved method of measuring financial gains of selected genetically improved stock began with a search for more accurate ways to relate tree characteristics with harvest revenues.

Most applications of economic analysis to forest genetics problems have focused on evaluating financial returns from entire research or seedling production programs. Several such studies are notable.

Early analyses sought to determine what rate of genetic gain would justify investment in tree improvement programs. Lundgren and King (1966) viewed accelerated growth rates from superior seeds as an apparent increase in site index of improved jack pine and red pine planting stock. For alternative rates of return ranging from 4 to 6 percent, they concluded that the gain in site index necessary to offset costs for tree improvement could be attained readily. For example, returns of approximately 7 percent were projected if site indexes of class 55 land could be increased by only 2 units.

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A study by Davis (1967) estimated the gains necessary to make southern pine improvement programs financially self-sufficient. An increase of only 1 cord at rotation, or its value equivalent in quality increase, was needed to offset net costs for superior seeds of approximately $10 per pound. Such volume increases were considered virtual certainties.

An analysis of the financial returns and increased future harvests from an accelerated forest genetics program for southern pine indicated a rate-of-return of 12.4 percent (Row 1967). In another study of improved southern pines, Swofford and Smith (1972) evaluated the economic advantages of the tree improvement program for the National Forests in the South. They expressed the results as aggregate implications for harvesting and inventory volumes. Improved trees would increase yields from National Forests in the South by 24 percent.

None of these studies developed estimates of gain for specific genetic characteristics. The first study that made notable improvements in this direction was Porterfield's (1974) application of goal programming to compute gains from public and private genetic improvement programs for loblolly pine. With this model, profit impacts of various roguing intensities and wildstand selection intensities were calculated. Goals were changed, absolutely or relatively, in response to assumed market conditions. Economic criteria included specified internal rates-of-return and benefit-cost ratios. Greatest profits accrued where many clones were selected, grafts were closely spaced, and orchards were intensively rogued.

Our approach diverges from these precedents in several respects. We have not attempted to evaluate tree improvement development programs, but to provide a tool for economic decision-making among genetic source material within a program. In this approach specific measures of genetic gain--increased height and diameter growth, improved form, and higher survival rates--are used to modify the component functions of existing stand models that project growth of unimproved plantations. The modified models can be used to simulate growth and yields of genetically improved plantations under different site quality, spacing, and management assumptions. This approach minimizes errors that occur when the design of genetic tests creates conditions that vary substantially from commercial plantations.

Previous projections of economic gain from genetic manipulation have relied on general percentage estimates of increased volume. This tends to minimize influences of tree and stand characteristics on stumpage price and harvesting costs. Yet, these characteristics have been shown to significantly affect the financial returns from timber growing (Row 1973; Dutrow et al 1970). Stand conditions that have particular influence are tree size and volume per acre. Values assigned herein reflect price functions that account for stand influences. The sensitivity of improved plantation to other factors, such as altered growth rates or costs, can also be ascertained.

Analytical advantages were made possible by use of a relatively new computer system called MULTIPLOY (Row 1974). It is a special computer language for evaluating a wide range of timber investments.

MODIFYING A GROWTH MODEL TO SIMULATE GENETIC GAINS

Forest mensurationists have developed numerous models for projecting timber stand development with varying levels of detail. In particular, Clutter and his associates at the University of Georgia have developed mathematical functions to describe the growth of unimproved loblolly pine plantations. We devised a procedure for modifying these functions for increased growth rates of genetically improved planting stock.

To demonstrate this approach we used estimates of probable gains calculated from data provided by the North Carolina State Cooperative Tree Improvement program. These data included 27 sets of tests of genetic crosses of loblolly pine, each with a check test and from 7 to 33 genetic crosses in each set. Each check and cross test had an average of 27 surviving trees. Altogether average growth values for 8-year remeasurements of some 472 genetic crosses were made available.

Increased height growth

A primary goal of genetic manipulation and an important selection criterion is improved height growth. The average height of each genetic cross was divided by the average height of the check test of unimproved trees to provide a height adjustment ratio. Distribution of height gains of superior trees is shown in ogive form in Figure 1. On the horizontal axis relative height increases or decreases (some trials were shorter than check trees) are depicted. The vertical axis shows the proportion of genetic trials that exceeded the relative increases in height. Average height increase was 3.5 percent, with a median of 2.6 percent. About 16 percent of the trials had height increases greater than 10 percent.

In projecting height in simulated stands, the estimated height at each age was multiplied by the increase ratio. The estimating equation for unimproved stands is:

$$\log_{10}(H) = 1.5469 - 11.406 / T + 10^{(2.9110 / T)} * (.76481 * \log_{10}(SI) - .83419)$$

where H is height of dominant trees, T is plantation age, and SI is site index (Lenhart and Clutter 1971). For each set of genetic trials, site index was derived from heights of the check trees by solving the formula above for SI, with H and T known.

Diameter increases

A second specific genetic characteristic is average diameter growth. A genetic diameter increase factor was computed from the ratio of average diameters of improved trees to check trees. Figure 2 shows the ogive curve of the distribution of diameter increase ratios. Average diameter increased 3.0 percent, with a median of 1.5 percent.

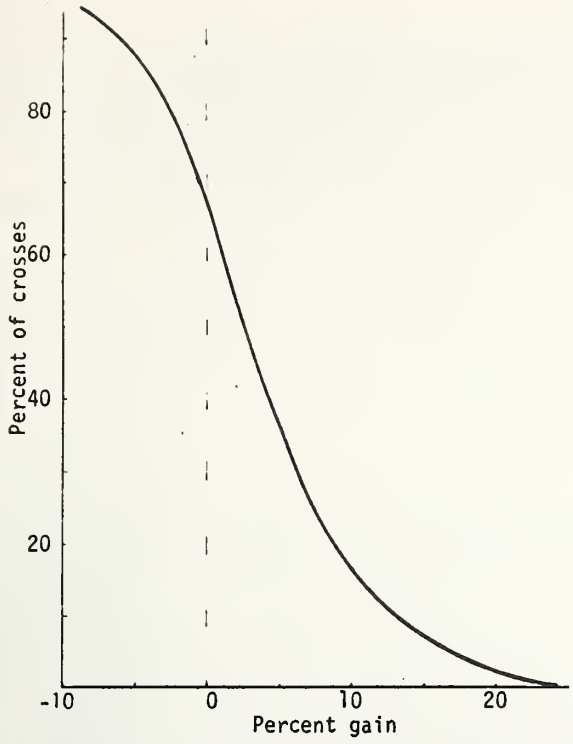

Figure 1.--Ogive of percent of crosses exceeding given percent gain in height.

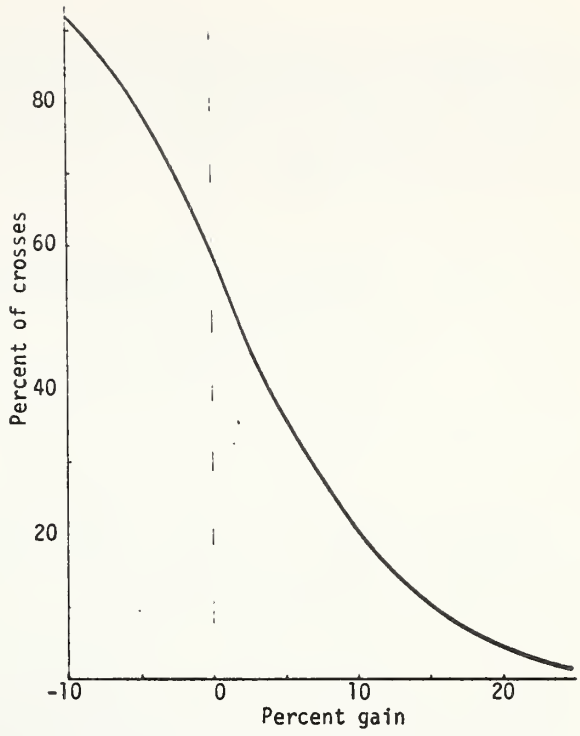

Figure 2.--Ogive of percent of crosses exceeding given percent gain in diameter.

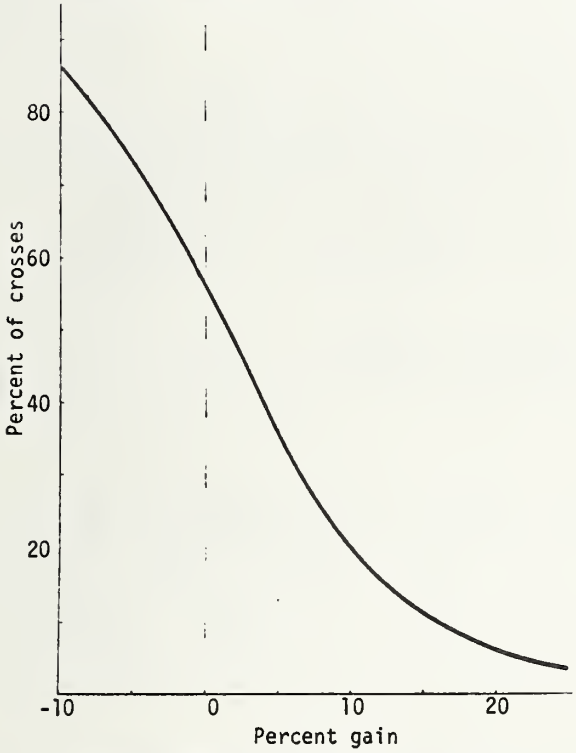

Figure 3.--Ogive of percent of crosses exceeding given percent gain in survival.

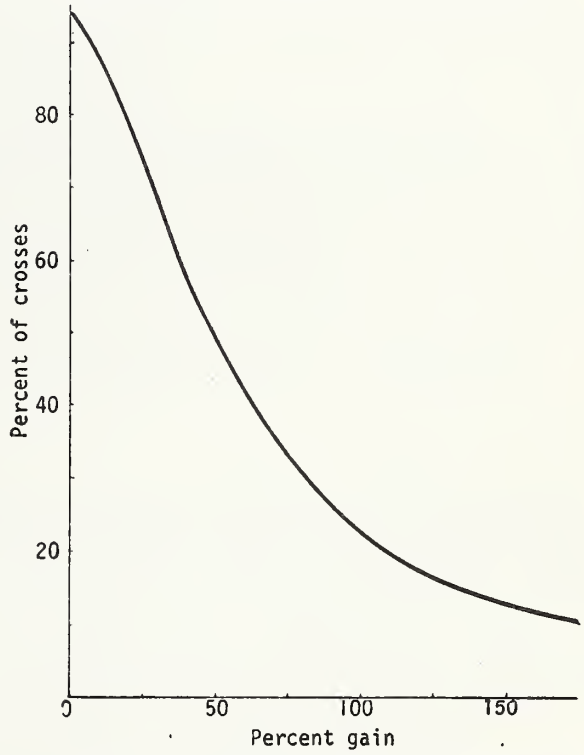

Figure 4.--Ogive of percent of crosses exceeding given percent gain in harvest value.

For projections of stand growth, this diameter adjustment factor was applied to expected minimum and maximum diameters of unimproved loblolly pine. Expected values were based on techniques developed by Lenhart and Clutter (1971) wherein a beta function is used to describe the distribution of basal area by diameter. The relative frequency of basal area occurring on stems with diameter D_1 is:

$$f(D_i) = \frac{\Gamma(\alpha + \beta + 2)}{(D_{max} - D_{min}) * \Gamma(\alpha + 1) * \Gamma(\beta + 1)} * \left(\frac{D_i - D_{min}}{D_{max} - D_{min}}\right)^{\alpha} * \left(1 - \frac{D_i - D_{min}}{D_{max} - D_{min}}\right)^{\beta}$$

where $f(D_1)$ is relative frequency of basal area occurring on stems with diameter D_1; D_{min} is the minimum diameter of trees in the stand; and D_{max} is the maximum diameter of trees in the stand. Alpha (α) and beta (β) parameters are functions of age and were not altered in our derivation of expected values of improved diameters.

MULTIPLOY divides the range between minimum diameter and maximum diameter into 20 intervals, computes the expected basal area in each interval, and converted this figure into the number of trees. Average diameter of the genetically improved stand was calculated from total basal area and number of trees.

Adjustments for change in volume relationship

Data from genetic trials enabled us to measure gains in height and diameter. These gains, however, may introduce changes in the form of the tree and anticipated merchantable volumes. Existing height-diameter-volume functions for plantations of unimproved loblolly pine had to be modified. Bailey and Clutter (1970) developed an original plantation volume function which was further transformed by Row (1973) into an aggregate stand function for plantation simulations. It has the form:

$$\log_{10}(Y/N) = -3.1193 + 1.7133 * \log_{10}(D) + 1.3836 * \log_{10}(H)$$

where Y/N is volume per tree.

Two steps were necessary to adjust this function for estimating volumes of genetically superior loblolly pines. First, the equation was used to compute expected volumes of the trees in the genetic improved trials. Second, recorded volumes of genetically improved trees were compared to the expected volumes calculated in step one. The comparison of recorded-to-estimated volumes was expressed as a volume adjustment factor to compensate for the changed form of genetically superior trees.

Volume adjustments were computed for each genetic cross and each check. Calculated averages and standard deviations of the volume differences were small but still statistically significant. Sixty percent of the adjustments

for crosses were within 5 percent of those for the check tests. The major benefit of deriving volume adjustment factors in the foregoing manner is that calculations for improved plantations blend measurements from genetic trials with observed growth rates of unimproved trees in plantation environments.

Survival of genetically improved trees

Although geneticists did not select loblolly seed sources for increased survival in plantations, our data suggested a difference in survival at age eight between the improved and check trees. An average survival rate of 91.7 percent characterized the genetic crosses, while the rate for checks was 86.3 percent. Survival rate distributions, however, appeared non-normal, and the variance of this trait was much higher than for the other measured characteristics.

We accounted for the difference in survival between selected and unimproved trees by transforming the survival rates into probit form. Probits computed for genetic trials were compared with probits computed for survival of check trials. The increase in survival of the genetic crosses compared with unimproved stock was statistically significant. The ogive curve for the distribution of survival probit increases is shown in Figure 3.

To calibrate our model for increased survival of improved plantations, probits were converted to probability estimates, P, such that P was the probability that natural plantations would have less survival than improved stock. Distribution of P would be uniform from zero to one only if survival rates of improved trees equaled those of natural plantations.

Studies by Lenhart and Clutter (1971) again provided a comparative basis with their expression for loblolly plantation survival distributions:

$$\text{Probit}(S) = 9.3745 - .67637 * \log_{10}(T) - .96269 * \log_{10}(N_o)$$

where S is the proportion surviving, T is the age of the plantation, and N_o the original number of seedlings planted per acre. The growth simulation routine in MULTIPLOY uses the generated P to compute survival at age 8 (to match the test measurements in this case) and expected survival rates at specified future years.

The combined effect of height, diameter, volume adjustment, and survival can be expressed in a general physical unit as change in volume. This net increase was computed for each trial by dividing total volume by the check volume. This net increase in volume was not used directly in the simulations, because the simulator could produce this data from the more specific characteristics.

An additional modification of the simulation system concerns the question of whether or not increased growth in early years of plantations of improved stock will continue at the same proportional rate. We did not attempt to answer this question in our model. Instead, several projections were made on a trial basis with a portion of the data. First with an optimistic outlook, improved rates of growth were assumed to continue until harvest. Second, as a pessimistic alternative, increased growth rates were assumed to regress toward normal rates according to a logarithmic function:

$$GG_{nj} = GG_{ni}^{(AA_i / AA_j)^F}$$

where GG_{nj} and GG_{ni} are average increases in the rate of growth during periods in which AA_i and AA_j are midpoint ages, and F is an adjustment factor.

We made trial runs with a portion of the data using F factors of 0. (no decline), .2, and .4. Though the levels of rates of increase changed substantially, the relationships between physical and financial returns were not affected.

Other modifications

The simulation model is capable of similar modification for specific gravity, but data from these 8-year old plantations with only juvenile wood were not available. Infection rates for fusiform rust, while available, can not yet be used to modify the plantation simulator with sufficient validity.

FINANCIAL RETURNS FROM CROSSES OF IMPROVED TREES

Using the modified plantation simulation model, MULTIPLOY estimated financial gains at the end of a 24-year rotation for the 472 individual genetic cross tests. Further assumptions were necessary:

Management regime

Plantations would be established on bare old-field sites or extremely well prepared cutover timber stands. Seedlings would be planted 500 to the acre. Fusiform rust infection would be at the average rate experienced in the tests. The plantations would be left unthinned until age 24 and then clearcut. By the nature of the plantations and rotation length, the primary product would be pulpwood.

Prices and costs

The value of timber produced at the single clearcut felling at age 24 was derived from an equation developed from stumpage sales of National Forest pulpwood and sawtimber by Row (1973). The modified equation is:

$$PU = -5.35 + 2.253 * D - .024 * D^2 + .452 * O$$

where PU is price in cents per cubic foot. It gives higher values for larger diameters and heavier cuts per acre. Revenues were discounted at 7 percent compound interest. Since no inflation in timber prices was assumed, this is equivalent to using a discount rate of 10 percent or more if prices rise at the rate timber prices have risen over the last several generations.

For this analysis, costs of plantation establishment would be the same for all comparisons, and were thus disregarded.

Results

Financial returns were computed for all simulations in terms of both present net worth, and equivalent annual income. (We did not use benefit-cost ratios, and rates-of-return. They were not appropriate since no costs were assumed.) As in the comparisons of physical genetic characteristics, the returns from the simulation using the genetic gain ratios for individual crosses were divided by the financial returns from the check tests.

The distribution of increases of present net worth for the 472 simulations is shown in Figure 4. The standard errors and coefficients of variation exceeded those for any of the genetic traits analyzed. The ogive curve for the distributions is relatively flat.

From a financial viewpoint, however, the results are highly gratifying. Many trials indicated financial gains of up to 150 percent, with the average gain of 73 percent and the median 50 percent. Only a few of the 472 simulations of genetic crosses indicated a poorer financial return than the check test data.

Dependence of financial returns on genetic traits

To determine the relationship of increased financial gains on specific genetic characteristics, a regression analysis was made. The dependent variable was the proportional gain in present net worth or income per acre, and the independent variables were the relative gains in each genetic trait, their squares, square roots, and simple crossproducts. The resulting regression equation was:

$$GV = 97.4409 + 10.3877 * GH^2 - 67.9319 * \sqrt{GH} - 51.4453 * \sqrt{GD} + 12.8150 * GD^2 * GH$$

where GV, GH, and GD were the proportional genetic gains plus 1 for value, height, and diameter respectively. The regression variables removed 89 percent of the variance, but the standard error of estimate was still .241, or 33 percent of the average genetic value gain. The gain in value was most closely related to gain in volume (or $GD^2 * GH$ in the equation), but this variable alone accounted for only 28 percent of the variance of value gain. Gains in survival and changes in form were marginally significant at the 5 percent probability level but added little to the accuracy of the equation.

A second measure of the effectiveness of the estimate of financial gain is to assume that the same genetic material as the best 30 percent of the crosses were to be used in commercial plantations, with correspondingly high rates of genetic

improvement. Cut-off points above which 30 percent of the crosses exceeded were determined from Figures 1, 2, 3, and 4, and average increases in value at the end of the rotation for all selected crosses computed. The results were:

Criterion	Cutoff point	Average value increase
Height	+ 6.1 %	+ 128.9 %
Diameter	+ 7.5 %	+ 133.0 %
Volume	+ 20.0 %	+ 135.9 %
Harvest value	+ 84.0 %	+ 160.5 %

Though by the method of computation, the average value increase using the harvest value criterion is the best, it is surprising that the differential is as large as it is.

A number of both genetic and economic factors could alter these results. Inclusion of assumptions or measured data on persistence of increased growth rates, increases in specific gravity of wood, and resistance to fusiform rust needs attention. And various owners may wish to assume differing value functions for harvested wood, and management regimes for plantations.

SUMMARY

The evaluation procedure we have developed is capable of appraising individual crosses and sources of genetically improved seed using expected financial returns from timber harvests. By modifying or calibrating mensurational models of plantation development, simulations of resulting timber stands can generate descriptive information by which relative unit values of the harvest can be estimated. Simulated financial returns using data from 472 genetic crosses of loblolly pine showed a complex and highly sensitive relationship to increases in height and diameter growth.

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POTENTIAL FOR FOREIGN PRODUCTION OF PINE SEED FOR THE UNITED STATES

H. Don Smith[1/]

Abstract. -- An attractive possibility exists for contract production in a foreign country of pine seed for use in the United States. Because domestic first-generation orchards have usually been established, the greatest opportunity exists with advanced-generation genetic material. The primary advantages of foreign seed production are:

1. Large quantities of extremely valuable seed could be available more quickly and cheaply than is possible in the United States.

2. The certainty of the magnitude of annual seed yield is greatly improved due to reduced yearly production variance.

INTRODUCTION

The breeding of pine trees for improved growth, form and disease resistance is a routine practice in the southern United States. Over 6,000 acres of production orchards are established (Knight & McClure 1974), with the oldest being approximately 20 years of age. The seed currently produced are sufficient to plant at least 400,000 acres annually, and within five years enough improved seed will be available to plant well over one-half million acres each year (Anon. 1974a, Anon. 1974b). At maturity, 6,000 acres of pine seed orchards should produce annually enough seed to plant over 4 million acres, a quantity probably sufficient to satisfy the annual planting needs of the South. Even so, there is a need to establish more pine orchards -- new, more genetically improved orchards that will make the current 6,000 acres of "first-generation" orchards obsolete.

Matziris (1974) has calculated the current superiority of 8-year-old first-generation trees over wild stock to be 15 to 19 percent in volume, 18 percent in disease resistance, and over 11 percent in straightness. But the predicted additional gains possible from second-generation breeding efforts are even greater (Table 3). With rapidly rising land and timber values in the southern United States, it is certain that the first-generation orchards should be replaced with superior second-generation material at the earliest opportunity. Only 28 acres of second-generation orchards are now established (Anon. 1974a), and none are old enough to bear commercial quantities of seed.

The southern pines, especially loblolly (*P. taeda*) and slash (*P. elliottii*), are grown in a number of foreign countries, such as Australia, Brazil, South Africa, and New Zealand. For reasons not entirely understood, these species yield larger and earlier seed crops in some countries than in the United States, and an example is shown in Table 1. There are three major reasons to consider

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second-generation tree seed production in foreign countries. (1) The cost of seed production may be lower. (2) It can be possible to obtain larger volumes of highly improved seed sooner than in the United States, and with more consistency. (3) Due to faster tree growth the possibility exists of accelerated generation turnover.

Establishment Procedures for First- and Second-Generation Orchards in the U.S. and a Foreign Country

The breeding method most used to create superior first-generation populations of southern pines is mass selection plus progeny testing. The degree of improvement possible from this procedure depends on the variance of the population, the phenotypic superiority of selected individuals, and the degree to which individual traits are inherited.

Phenotypic selection is inefficient in that phenotypes do not always accurately indicate genotypes, i.e., a phenotypically superior individual sometimes produces inferior progeny. Progeny testing is a refinement of the initial selection process, and accurately reflects the performance of certain matings when the offspring are grown in a particular locality. Parent trees that are inferior based upon progeny tests for a locality are rogued -- removed -- from the orchard. Therefore, the total improvement derived from a first-generation orchard is from the initial gain from mass selection plus the refinement of the initial choices through progeny testing.

Second-generation orchards will provide additional gain over that obtained in the first-generation. The elite population derived from mass selection and progeny testing is used as a breeding base to provide control-pollinated "families" in which both first-generation parents are known. The most outstanding individuals within the best families are vegetatively propagated to be used as parents in second-generation seed orchards. Good precision is possible in choosing superior individuals and predicting the performance of the progeny in the second-generation because of knowledge about the genetics of families and of individuals as well as from the greater uniformity of site and spacing in planting. Once a pedigree has been established for each individual and a better environment created for selection, efficiency and gains are rapidly improved.

If second-generation seed for the U.S. were to be produced in a foreign country, one of two procedures would have to be used: (1) Vegetative material (scions) from the appropriate individuals would be sent to the foreign country where it would be used to form vegetative orchards similar to many in the U.S. Only the location of the orchard would be different, and the seeds produced for return to this country would be genetically identical to those produced domestically from the same parent trees. Currently, however, the governments of most countries, including the U.S., will not allow free importation of vegetative tree material for fear of disease introduction. Sterilized seed is usually permitted to enter a foreign country. (2) In lieu of scion introduction, seed of the same genetic crosses that produced the superior control-pollinated families in the U.S. could be sent to the foreign country. There it would be grown as in the U.S., but it is not certain that selection of the best individuals within the best families would always be valid. Geneticists use the term "genotype-by-environment interaction" to describe the situation

where individuals behave distinctly differently -- perhaps change rank within a group -- depending on the environment in which they are grown. Where this problem exists for certain characteristics, especially growth or disease resistance, individuals selected for superiority in a foreign country may not be superior when grown in the U. S. Thus a portion of second-generation gain due to selection of individuals within the best families may be lost.

Comparative Foreign and Domestic Seed Yields

Southern pines sometimes yield more seed, and with less annual variance, in foreign countries. For example, Tables 1 and 2 illustrate typical orchard yields for both South Africa and the U. S. It is clear that in these typical U. S. orchards there is extreme year-to-year variation, and there is also considerable variation between orchards. Reports from S. A. and some other countries indicate their yields are very stable from year to year, and with proper selection of orchard location, yields are predictable and consistent between orchards.

Table 1. -- Comparison of South African and U. S. orchard yields of loblolly pine seed [a/]

Age	SA	C_1	C_2	C_3	P_1	P_2
	Pounds/Acre					
3	---	.07	2.30	---	.50	---
4	1.70	.02	3.00	---	.80	---
5	7.20	5.30	4.00	---	1.40	---
6	36.00	8.30	12.70	---	5.30	---
7	42.80	10.30	16.80	---	7.00	---
8	99.40	14.20	22.00	---	---	---
9	106.30	13.40	---	9.28	---	16.67
10	111.40	21.50	---	13.93	---	24.11
11	---	---	---	14.86	---	40.89
12	---	---	---	50.86	---	30.67

SA = South African Orchard -- loblolly pine.

C_i = Coastal sources of U. S. loblolly, representing various orchards.

P_i = Piedmont sources of U. S. loblolly, representing various orchards.

[a/] Sources: S. A. yields were furnished by Mr. Neville Denison of S. A. Investments Ltd., and represent actual loblolly seed yields from orchards in that country. Other yield figures are production records from typical orchards in the southeastern U. S.

For purposes of comparison, a composite profile of typical yields of U. S. loblolly orchards was prepared (Table 2). Harvest costs are based on a recent survey of members of the N. C. State Tree Improvement Cooperative.

The Question of Genotype-x-Environment Interaction

Without knowledge of the effect of GE interaction on selection it would not be safe to do within-family selection in a foreign country. Unless GE interaction is shown not to be a serious problem, about 40 percent of the possible gains from second-generation breeding might be lost by producing seed in a foreign country because of the inability to choose the best individuals within families (Table 3). Some information is now available to help determine the magnitude of the GE interaction.

In 1970, seed from selected clones of loblolly and slash pines grown in South Africa were sent to the U. S. for testing. At the end of one year, of the top 50 percent in height growth, four of six families were listed in the top 50 percent in both the U. S. and in S. A. Four-year measurements will soon be available and more definite comparison of family rank between countries can be made. It is evident by observation that nearly all these families selected for superiority in S. A. have grown extremely well in the U. S. Three-year measurements are available for progeny grown in Rhodesia from seed sent from the U. S., and a number of the best-performing families in Rhodesia are also top performers in the U. S.

Table 2. -- Composite profile of seed yield per acre in a typical U. S. loblolly seed orchard and the associated harvesting cost per acre

Age	Yield/Acre (Lbs.)	Harvesting Cost/Acre
5	7	$158
6	10	192
7	13	226
8	19	295
9	27	387
10	33	456
11	37	501
12+	40	536

All available data offer little more than a general indication about the GE interaction question. The most comprehensive answer will come from a unique test now being established through the N. C. State Cooperative Programs. Seed have been selected from over sixty clones known to perform well when mated with nearly any other parent (Good General Combiners). These are being used in test plantings across the South by 28 companies, and in six foreign countries. In a few years these tests will give solid indication of the extent of the GE interaction problem across the South and among areas of four continents.

Based upon data available, this writer must assume that intelligent location of southern pine family tests in foreign countries where the species grows well will allow reasonably accurate within-family selection for second-generation material that is to be repatriated to the U. S.

Predicted Genetic Gains From Second-Generation Selections

Matziris (1974) has estimated the genetic variance components and correlations at age eight from first-generation loblolly pine progeny tests in nine separate locations across the South. The values are reasonably consistent across locations, though sometimes statistically different. Within a location the statistical significance of estimates is good.

These numbers were used to estimate the values in Table 3, which are predicted gains that could be obtained by selecting for each trait individually under normal U. S. breeding practices.

Table 3. -- Predicted additional gains (%) in single traits under different breeding procedures from second-generation orchards in the U. S.

	A	B
Height (Ft.)	5.3	8.7
Straightness (Score)	8.2	14.7
Volume (Cu. Ft.)	9.0	25.0
Fusiform (Score)	21.5	35.0

A = Selection of top 25% of families.

B = Selection of top 25% of families plus additional selection of top 3 percent of individuals within families.

There is a definite limit to the selection intensity that can be applied for second-generation selection, which is dependent on the number of families and individuals per family that are under test. Current procedure with the N. C. State Tree Improvement Program is to select about the top 25 percent of families, and the top 3 percent of individuals within families. With these selection intensities the average predicted gains to be expected in single traits from breeding within the U. S. are shown in Table 3. Column (A) shows predicted second-generation gains from family selection alone, and (B) the gain from selection of families plus within families. Roughly 60 percent of the total predicted second-generation gain from breeding within the U. S. comes from family selection; the rest is from within-family selection.

The predictions in column (A) would also be the minimum gain to expect from seed produced in a foreign country, since the family selection would occur in the U. S., and the seed would come from these same family groups in the foreign country. However, the predicted gains in column (B) could only be achieved in a foreign country if there is no genotype-by-environment interaction. To the degree that this interaction does exist, selection within families will be inefficient and the gain reduced for seed to be returned to the U. S. Selection within families for fusiform rust resistance would be very difficult to achieve in a foreign country because the pathogen exists only in the U. S. No natural infection could occur and the only way a selection differential could be obtained would be through screening individuals by artificial inoculation with fusiform spores. This is one current method of determining fusiform rust-resistant families in this country, but it is doubtful any foreign country would accept the procedure. Although fusiform rust

requires a life-stage on red oak trees, and there are no natural oaks in many foreign countries, it is possible for a mutant spore to find another related hardwood species an acceptable alternate host. One feasible method of identifying the fusiform susceptibility of parent trees growing in a foreign country would be to send seed from individuals to the United States for testing. Facilities for laboratory testing for disease resistance are available now in the United States and the cost per test is insignificant. It does remain to be determined how well laboratory tests compare with field results, but early results are encouraging. The primary point to note is that the economic value of seed does depend on the level of fusiform intensity in the area for which the seed are intended, and the degree of genetic resistance carried by the seed. Furthermore, the degree of resistance is dependent on the ability of the tree breeder to accurately select disease resistant parent trees.

ECONOMIC ASSESSMENT

Seed Production Costs

Cost figures for an "average" orchard which were derived from a TAPPI (Technical Association of the Pulp and Paper Industry) survey of 19 industries in the Southern Pine Region are used to reflect the costs that will be involved with second-generation orchards. Costs of making new wild selections, controlled crossing, and progeny testing are ignored because these will be borne by the U. S. companies regardless of where the second-generation orchard is established. The relevant comparative seed production costs are shown in Table 4.

An inflation-free real rate of return (Mundell 1963) was used to calculate annualized average U. S. seed costs that could be compared with the real average annual cost of seeds from S. A. Based on the seed yields of U. S. loblolly orchards, the discounted annualized after-tax cost per pound of seed is $14.81 at a 10 percent real rate of return. Foreign companies have estimated that they could produce loblolly seed for about $13.50 per pound in constant 1974 dollars, or an after-tax cost of $7.02 in constant dollars for a large company who might purchase the seed.

In relative terms the cost of loblolly seed purchased from a foreign country could be about 50 percent cheaper than seed grown domestically. For a company that needs 2,000 pounds of seed annually (the expected mean yield from a mature 50-acre U. S. loblolly orchard) the average saving in seed cost could be about $15,600 per year in current after-tax dollars. But cost of seed production is only one side of the coin -- the other is the benefit to be derived from seed produced in either the U. S. or a foreign country.

Seed Valuation

The value of a pound of improved seed is the discounted net present value of the additional wood produced by it in an on-going planting program. In Tables 5 and 6 these values are estimated for both domestic and foreign-produced seed when the seedlings are grown under various degrees of fusiform intensity.

Table 4. -- Seed production costs associated with a 50-acre second-generation loblolly seed orchard in the southern U. S. *

	Before Tax	After Tax
Orchard:		
Site preparation and establishment [a/]	$13,150	$ 6,575
Management cost/year [b/]		
1-5 years	7,650	3,825
6-10 years	12,850	6,425
11+ years	16,950	8,475
Land value, 50 acres	5,950	5,950
Annual property tax on orchard land	32	16
Harvesting: [c/]		
age 5	7,900	3,950
6	9,600	4,800
7	11,300	5,650
8	14,750	7,373
9	19,350	9,675
10	22,800	11,400
11	25,050	12,525
12+	26,800	13,400

[a/] Land clearing, burning grafting, planting stock trees.

[b/] Fertilization, mowing, insecticides, supervision, etc.

[c/] Cone collection, seed extraction, and cleaning.

* Adapted from TAPPI data shown in Porterfield (1973).

Let us assume that a company needs 2,000 pounds of loblolly seed annually, which may be produced domestically in the usual fashion; alternatively, it can contract for enough acreage in a foreign country to yield an identical quantity of seed. The present value of the total amount of seed depends on:

1. Degree of genetic improvement over first-generation seed.
2. Life of the orchard, which will be set at 25 years.
3. Base productivity of the land on which the seed will be planted, assumed here to be 160 cubic feet per acre per year with first-generation material.
4. Degree of disease hazard. The present value of seed intended for a hazardous area is less than for a nonhazardous area.
5. Harvest age of the plantations, assumed to be 25 years.
6. Acres planted by each pound of seed; the number used is 16 acres.
7. Real alternative rate of return, which will be set at 10 percent.
8. Stumpage value of wood produced, taken to be constant at $.50 per cubic foot.

If GE interaction is a problem in a foreign country, then the appropriate comparison of alternatives is Method A in the foreign orchard with Method B in the U. S.; under conditions of no fusiform, the present value of the U. S.-produced seed exceeds that of the foreign-grown by $3,130,000. Under these circumstances it would not make economic sense to produce seed outside the U. S. But if little GE interaction is present, enabling foreign within-family selection for traits other than fusiform, then the present value of the foreign-produced seed exceeds that of U. S. seed by $557,000 under conditions where fusiform rust is of little importance.

Table 5. -- Present value of the additional wood obtained from second-generation seed produced from a domestic orchard over a 25-year life

Method A (Family Selection Only)				
Fusiform Intensity	None	Light	Medium	Heavy
After-tax net present value of 1 lb. of seed @ 10%	$213	$190	$140	$126
After-tax present value of all seed received for 25 years	$1,767,000	$1,576,000	$1,162,000	$1,045,000

Method B (Family Plus Within-Family Selection)				
Fusiform Intensity	None	Light	Medium	Heavy
After-tax net present value of 1 lb. of seed @ 10%	$618	$560	$442	$378
After-tax present value of all seed received for 25 years	$5,128,000	$4,646,000	$3,667,000	$3,136,000

Table 6. -- Present value of the additional wood obtained from second-generation seed produced from a foreign orchard over a 25-year life

Method A (Family Selection Only)				
Fusiform Intensity	None	Light	Medium	Heavy
After-tax net present value of 1 lb. of seed @ 10%	$220	$197	$147	$133
After-tax present value of all seed received for 25 years	$1,998,000	$1,789,000	$1,335,000	$1,208,000

Method B (Family Plus Within-Family Selection)				
Fusiform Intensity	None	Light	Medium	Heavy
After-tax net present value of 1 lb. of seed @ 10%	$626	$580	$473	$400
After-tax present value of all seed received for 25 years	$5,685,000	$5,267,000	$4,295,000	$3,633,000

The relative situation is little changed when seed are intended for areas of heavy fusiform infection. With severe GE interaction it would not make economic sense to contract for foreign seed production, but without GE problems it would be profitable. The situation seems to be that if foreign orchards can be established by vegetative means, in which case the GE problems are eliminated, there is a possibility of large gain by U. S. forestry corporations. If scion importation is forbidden, and foreign orchards must be produced from seed, then potential gains are directly related to the degree of GE interaction that occurs. Appropriate testing can eliminate much of this problem, but probably not all of it. Because of the amazingly large spread between seed production costs and the value of the seed to a wood-producing company, the issue of key importance becomes the rapidity by which improved seed can be obtained, not the cost of production.

The most satisfactory solution to the foreign seed production problem would be to develop mutually satisfactory scion exchange procedures with some foreign countries. In this way all question of GE interaction could be eliminated, and the financial gains from obtaining highly improved seed more quickly could be considerable. But even if scion exchange continues to be a problem, with the correct procedures, foreign seed production for use in the U. S. could be worthwhile.

SUMMARY

An attractive possibility exists for contract production in a foreign country of pine seed for use in the United States. Because domestic first-generation orchards have usually been established, the greatest opportunity exists with second-generation genetic material. The primary advantages of foreign seed production are:

1. Large quantities of extremely valuable seed would be available more quickly than is possible in the United States.

2. The certainty of the magnitude of annual seed yield is greatly improved due to reduced yearly variance.

3. The cost of seed production in a foreign country such as South Africa would be lower than in the United States if current cost differentials continue.

4. Acceptable scion export procedures would allow the greatest advantage to be made of foreign seed production possibilities.

The disadvantages to foreign seed production:

1. Selection of genotypes in a foreign country for use in the United States may not be efficient if large genotype-x-environmental interaction exists, although circumstantial evidence to date suggests that this will not be a serious problem.

2. Effective selection for fusiform rust resistance is more difficult outside the United States.

3. If a seed source is located outside the United States, supplies could be interrupted by political or social upheavals over which the United States company would have no control.

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SELECTING POPULATIONS OF LOBLOLLY PINE FOR RUST RESISTANCE AND FAST GROWTH

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Abstract.--Loblolly pine from Livingston Parish, Louisiana, has proven to be rust resistant and fast growing after 20 years in plantings in southern and central Mississippi, Alabama, and Georgia. Loblolly from eastern Maryland is also resistant and has grown relatively fast between the 10th and 20th year in the same plantings. Maryland seed sources would probably be best for planting in the Piedmont of Alabama, Georgia, and South Carolina, where the climate is too severe for Livingston Parish loblolly.

A useful level of rust resistance is found in the loblolly population north and west of Livingston Parish as far as Adams County, Mississippi, a distance of about 80 miles.

Additional keywords: Fusiform rust, seed source x planting location interactions, provenance selection, Pinus taeda.

Within 10 years practically all the pine seed for plantations in the South will derive from orchards of selected trees. In the meantime, selection of geographic seed source is a valid means of attaining genetic gains at minimal cost. For example, loblolly (Pinus taeda L.) from Livingston Parish (southeastern Louisiana) offers both rust resistance and fast growth when planted on high rust hazard sites along the Atlantic and Gulf Coastal Plains. This application is based on 10- and 15-year results of the Southwide Pine Seed Source Study (Wells 1969). The study has since been remeasured after 20 years in the field, and results for loblolly pine are presented here. In addition, results from an intensive sampling study of loblolly pine (Wells and Switzer 1971) are used to determine the geographic limits of the rust-resistant population near Livingston Parish, Louisiana, and in southwestern Mississippi. Results presented here should help forest managers procure the large amounts of seed they need and insure that its genetic quality is as high as practicable.

MATERIALS AND METHODS

Southwide Pine Seed Source Study

Complete details of the loblolly phase of the Southwide Pine Seed Source Study are given by Wells and Wakeley (1966) and Wells (1969). Fifteen seed sources are represented, and 16 plantings survive afer 20 years in the field (fig. 1). The seed sources and plantings are divided into two series. Series-1

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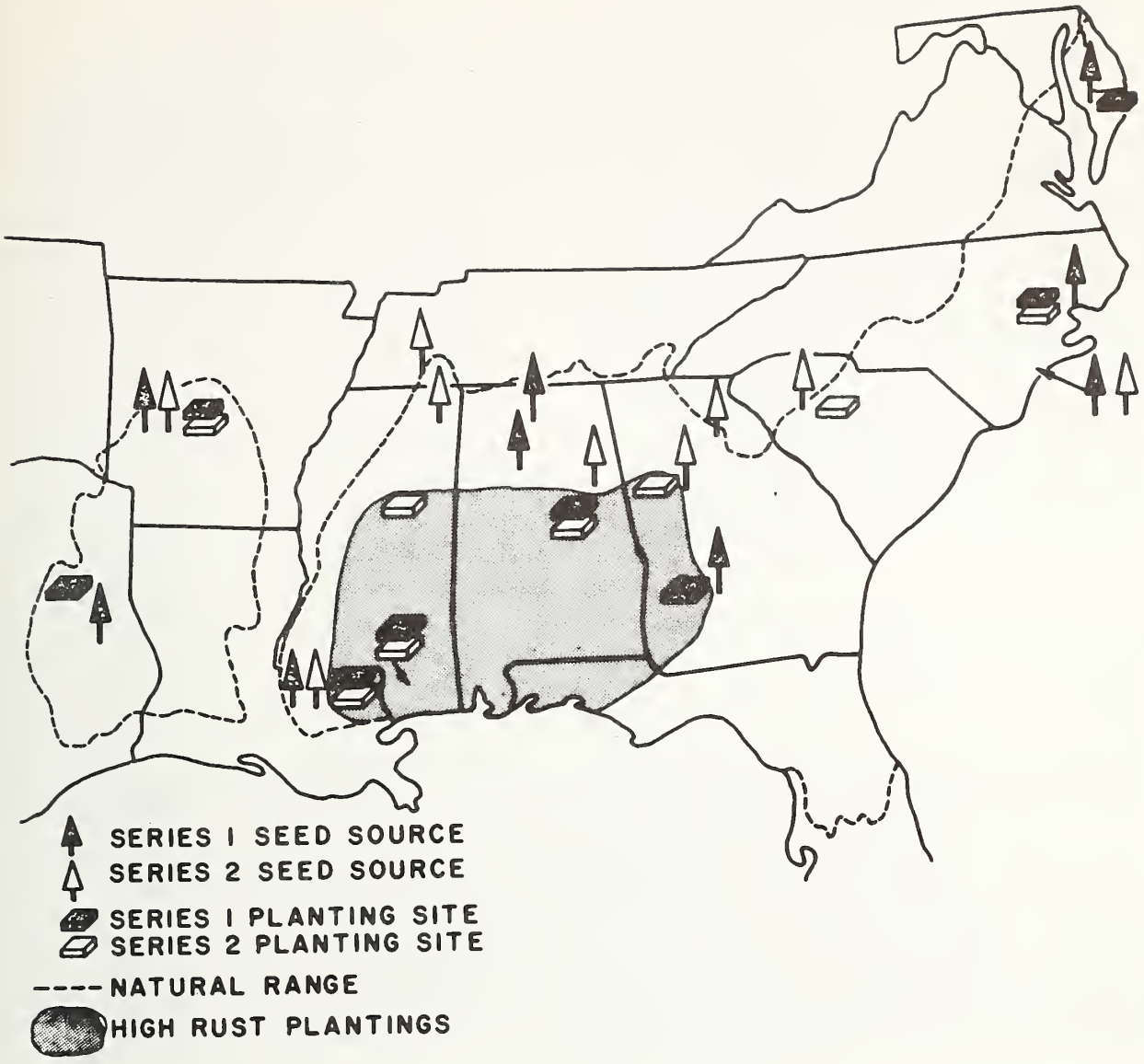

Figure 1.--Location of 15 seed sources of loblolly pine and the plantings in which they are represented. Southwestern Arkansas, southeastern Louisiana, and southeastern North Carolina sources are in both Series-1 and Series-2 plantings.

sources represent the major part of the range. Series 2, with the exception of the southeastern Louisiana seed source, is restricted to an east-west transect from North Carolina to Arkansas. Seed was collected in 1951 from at least 20 trees in each area, and seed from all trees within a source was composited. A randomized complete-block design with four replications was used for each planting. Plots consist of 121 trees at 6- by 6-foot spacing; the inner 49 trees

were periodically measured, and the outer two rows served as borders. Height, amount of rust infection, and several other traits were measured at ages 1, 3, 5, 10, 15, and 20 years. Through age 10, amount of rust infection was expressed as the percentage of trees per plot with stem or branch galls; only trees with stem galls were counted. Amount of rust infection at age 10 is considered the most reliable indicator of seed source differences since loss of galls through shedding of lower limbs is minimal at this age.

Intensive Sampling Study

In 1962 and 1963, seed was collected from five randomly selected trees at each of 115 locations in and near Mississippi. To focus attention on the loblolly population near Livingston Parish, progenies from only 35 locations are considered here. Plantings were established during the winter of 1965-66 in Livingston Parish, central Mississippi, and northwestern Alabama; each seed collection area was represented by a 10-tree row plot in each of 10 replications. Only the Livingston Parish planting survived well enough (73.4 percent after 5 years) to give statistically precise results. The average number of galls per tree was determined at age 4, and total height was measured at age 5.

In both studies, total height rather than volume is considered the most reliable indicator of genetic differences in vigor among seed sources as it is not biased by differences in stocking.

Analyses

Analysis of variance and multiple range tests at the 0.05 level of significance were performed as described in Wells and Wakeley (1966) for the Southwide Study and Wells and Switzer (1971) for the intensive sampling study. Data from the four Series-1 Southwide Study plantings in Mississippi, Alabama, and Georgia were pooled as were data from the five Series-2 plantings in the same area (shaded area, fig. 1) because seed source performance was similar in all these plantings. For convenience we refer to these plantings hereafter as the high rust zone plantings (HRZP). Seed source rankings for height differed substantially in each of the Southwide Study plantings outside the HRZP; so results in them are presented by individual plantings.

RESULTS AND DISCUSSION

Southwide Pine Seed Source Study

In the high rust zone plantings, the major geographic variation in growth rate is between trees of coastal origin on one hand and continental and western trees on the other (figs. 2 and 3). After 20 years in the field, the differences in height between these two groups is about 4 feet in Series 1 and 5 feet in Series 2. Coastal trees are remarkably uniform in height whether they evolved in Maryland, North Carolina, Georgia, or Louisiana. Rust infection at age 10 was lowest among trees from Maryland, southeastern Louisiana, east Texas, and southwestern Arkansas (figs. 2 and 3), and later data (Grigsby 1973) confirmed

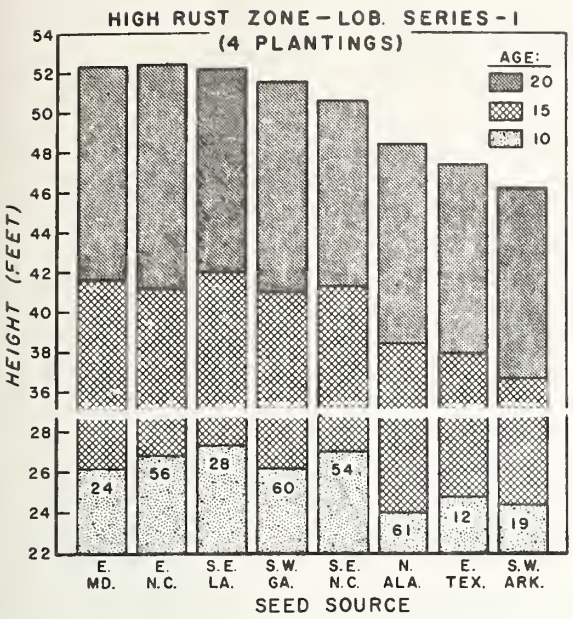

Figure 2.--Average height at three ages of loblolly pines from eight geographic seed sources. Number within bar indicates rust infection at age 10. Approximate Duncan's Least Significant Range at 20 years = 2.6 feet.

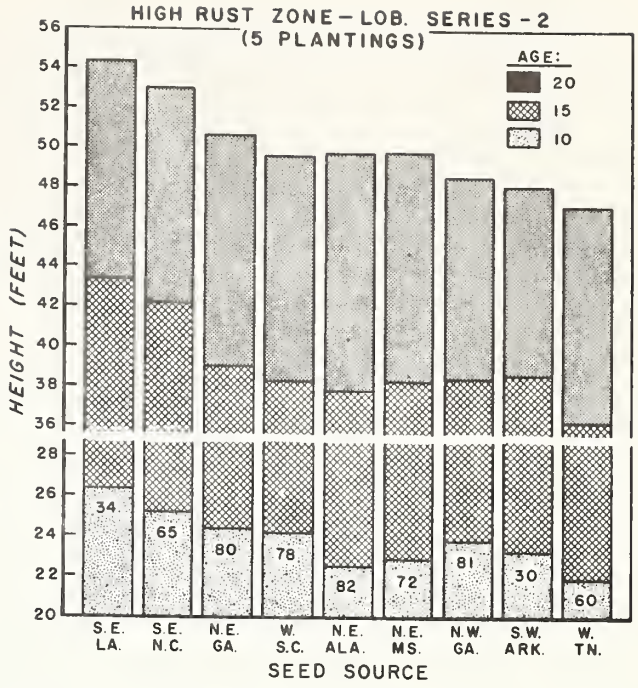

Figure 3.--Average height at three ages of loblolly pines from nine geographic seed sources. Number within bar indicates proportion of trees with rust infection at age 10. Approximate Duncan's Least Significant Range at 20 years = 2.2 feet.

their superior resistance. However, the Texas and Arkansas populations had slow growth rates. The best combination of fast growth and rust resistance in the HRZP was offered by the southeastern Louisiana trees. This population would probably perform well also in central and southern Georgia and coastal South Carolina, where the climate and physiography are similar to that in the HRZP. It is actually growing well as far north as coastal North Carolina, but unless rust is a serious threat there is no reason to move it that far.

Northeast of the HRZP are plantings in the Piedmont of South Carolina, the Coastal Plain of North Carolina, and the eastern shore of Maryland. Differences among seed sources are not significant in the South Carolina Piedmont, but as the southeastern Louisiana trees rank last it seems best to assume they should not be planted there. Instead, loblolly from the eastern shore of Maryland would be a good choice for this area and for the Piedmont of Alabama and Georgia, where rust is a serious problem. The Maryland population has considerable rust resistance, and it apparently is not cold susceptible since it does well farther inland in Tennessee (Rink and Thor 1971). In addition, it has a desirable growth rate as evidenced by its performance in the HRZP (fig. 2).

In the North Carolina Coastal Plain, coastal trees generally excell except for those from Maryland, which rank next to last. Twenty-year results in this planting show no reason to change the recommendation that Carolina loblolly seed can be moved parallel to the coast anywhere within North or South Carolina as long as Coastal Plain seed is used in the Coastal Plain and Piedmont seed is used in the Piedmont (Wells 1969).

Farther north in Maryland, the superiority of the Maryland loblolly has been striking from the start, and 20-year results in this planting strengthen this point.

West of the HRZP, coastal loblolly is also growing faster than continental or western trees, but in the southwestern Arkansas planting, growth of the Louisiana trees has slowed during the last 10 years, and they have been surpassed by trees from other coastal sources (table 1). Apparently southwestern Arkansas is just past the climatic limit at which the Louisiana trees can fully express their inherent growth potential. In this planting, trees from the Atlantic Coast are considerably taller than those from local sources, and the possibility of exploiting this geographic variation is being investigated (Grigsby 1973). However, forest managers contemplating such seed movements have to weigh the chances of poor initial survival of the Atlantic Coast loblolly against its fast growth rate. In both the Arkansas and east Texas plantings, survival at age 10 was 21.5 percent higher for local seed sources than for coastal North Carolina and Maryland seed. These plantings were established in a drought year, and mortality was heavy in both. In Texas early mortality reduced the planting to only two replications; so statistical precision is poor; but the Maryland trees appear to be poorly adapted since they are almost 10 feet shorter than the other coastal trees.

Intensive Sampling Study

Results in the Livingston Parish planting after 4 and 5 years (fig. 4) show that useful levels of rust resistance in the loblolly population extend north as far as Adams County, Mississippi, a distance of about 80 miles, although the Livingston Parish trees themselves are more resistant than those from any of the other points sampled. Resistance decreases to the east until in Washington and St. Tammany Parishes it reaches a point where the loblolly would probably not be useful for planting in high rust hazard areas (see also Crow 1964). The middle of Tangipahoa Parish would probably be a practical eastern boundary for seed collection in the rust-resistant population. To the south and west of Livingston Parish are hardwood swamps.

The pattern of 5-year height suggests genetic differences in vigor within the rust-resistant population. For example, trees from the southern portions of St. Helena and Washington Parishes are slower growing than those from other collection points. These height differences would probably not be important to a firm urgently seeking rust resistance; but if the time and effort necessary to select individual stands combining rust resistance and fast growth rate could be expended, genetic gains in both these traits could likely be made.

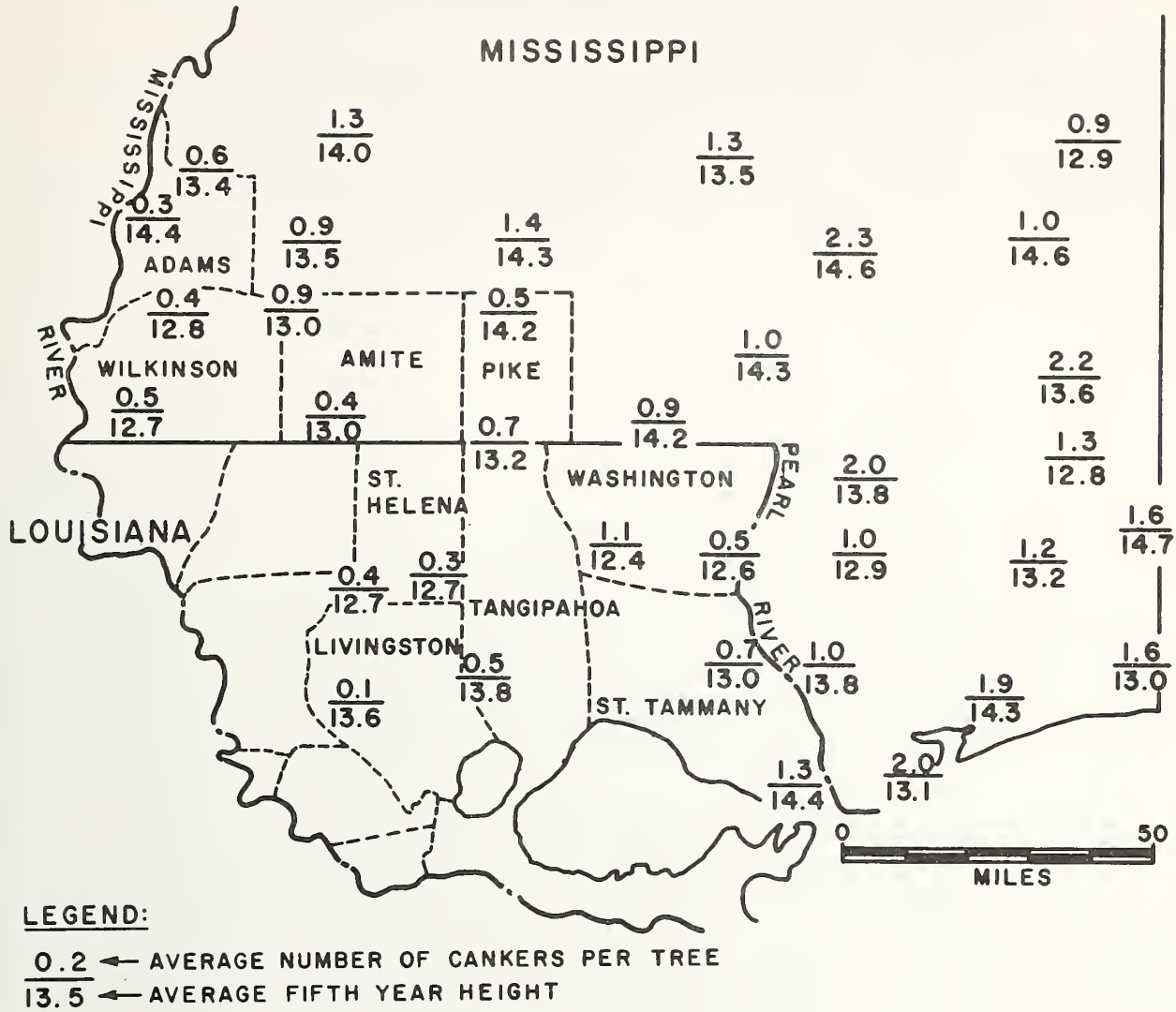

Figure 4.--Average number of cankers per tree and average 5th-year height for the progenies of 35 stands of loblolly pine grown in Livingston Parish, Louisiana. Approximate Duncan's Least Significant Range = 0.2 cankers per tree and 1.7 feet.

There appear to be no other sizeable geographic areas where rust-resistant loblolly seed could be collected in large quantities between southeastern Louisiana and Maryland or Virginia (Wells and Switzer 1971, Grigsby 1973, Goggans et al. 1972, and Kraus 1967). Therefore, southern forestry firms should intensify their efforts to collect greater quantities of seed from the southeastern Louisiana-southwestern Mississippi loblolly population.

Table 1.--Height at age 20 of loblolly pines from various geographic seed sources. Means opposite the same line are not significantly different at the 0.05 level.

Planting location and (series)	Seed source	Height
SW AR (1&2)	SW GA	60.3
	E NC	59.9
	SE NC	59.5
	E MD	58.7
	N AL[a]	57.9
	W SC	57.4
	NE GA	57.1
	N AL[b]	56.8
	SE LA	56.6
	NE MS	56.2
	NE AL	54.6
	W TN	54.3
	E TX	52.0
	SW AR	50.9
E TX (1)	SW GA	60.5
	SE LA	59.5
	SE NC	57.1
	E NC	56.8
	SW AR	56.8
	E TX	55.8
	N AL	54.6
	E MD	50.9
High Rust Zone (1)	E NC	52.3
	E MD	52.3
	SE LA	52.2
	SW GA	51.5
	SE NC	50.6
	N AL[a]	48.4
	E TX	47.4
	SW AR	46.2
High Rust Zone (2)	SE LA	54.3
	SE NC	53.0
	NE GA	50.7
	W SC	49.7
	NE AL	48.9
	NE MS	48.9
	NW GA	48.6
	SW AR	48.2
	W TN	47.2
Piedmont SC (2)	NW GA	49.1
	NE GA	48.2
	W SC	46.6
	NE MS	46.1
	W TN	46.0
	SW AR	43.8
	SE NC	43.4
	NE AL	43.0
	SE LA	40.5
Coastal NC (1&2)	E NC	57.9
	SE NC	57.5
	SE LA	56.9
	N AL[a]	55.7
	W SC	55.2
	NE GA	54.0
	NE AL	53.8
	E TX	53.2
	SW GA	52.9
	NE MS	52.7
	NW GA	52.6
	SW AR	51.1
	E MD	51.0
	W TN	49.7
E MD (1)	E MD	53.4
	E NC	50.6
	SE NC	49.7
	N AL[b]	47.7
	N AL[a]	46.5
	SW AR	46.2
	E TX	45.8
	SW GA	44.7
	SE LA	42.0

[a] Jefferson County, Alabama
[b] Cullman County, Alabama

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TREE IMPROVEMENT ON MARGINAL SITES

Clark W. Lantz[1/]

Abstract.--Marginal forest sites represent a vast untapped natural resource in the south. At least 25 million acres of low quality hardwood sites have the potential of commercial production. The production of short-rotation pine timber crops on these areas is one direct means of increasing wood supplies from a diminishing land base. An example is presented of a study in Oklahoma of the conversion of a "Cross-Timbers" area (post and blackjack oak) to pine. The first year survival and growth of planted shortleaf, loblolly and Virginia pine seedlings was excellent. Two exotic species (Pinus brutia and P. pinaster) have not survived well.

Additional keywords: Forest type conversion, herbicides, aerial spraying, direct seeding.

INTRODUCTION

The demand for wood and wood products will continue to increase. Reliable estimates of this demand indicate that by the year 2000 (only 25 years from now!) the population of the United States will have increased to more than 300 million (Southern Forest Resource Council, 1970). These estimates also indicate that the total consumption of paper will double by the year 2000 (Seaton et al, 1973) and that the demand for all other wood products will also double (Southern Forest Resource Council, 1970).

How can we produce enough of the raw material (timber, wood, fiber) to meet this demand? Four major alternatives are listed in the Report of the President's Advisory Panel on Timber and the Environment (Seaton et al, 1973):

1. Import more timber and export less.
2. Use less timber.
3. Make better use of the timber available.
4. Grow more timber.

Alternatives 1, 2, and 3 are clearly within the realm of legislation, economics, and manufacturing. However, as tree breeders and forest managers, we can work with alternative number 4. Certainly we need to maximize growth on our most productive sites. The total acreage in these high productivity areas continues to decrease however. For example: from 1962-1970, 20 percent of the South's bottomlands were cleared for row crop production (Seaton et al, 1973). Much of this was in response to the strong demand for soybeans. When beef prices were high, many good pine sites were cleared for pasture. Pressures from concerned "environmentalists" (justified and unjustified) have limited wood production on many areas. The net result of all of these factors is a continual reduction in the productive forest area in the South.

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The total commercial timberland in the South in 1970 amounted to 192 million acres (U.S. Forest Service, 1973). This is land which has been classified as capable of producing industrial wood and not withdrawn from timber utilization (wood growth of at least 20 cubic feet per acre per year). The productivity of this commercial timberland is outlined in Table 1.

Table 1. Productivity Classes of Commercial Timberland in the South (1970)

Productivity in Cubic Feet Per Acre Per Year	Million Acres	% of Southern Commerical Timberlands
120 +	13	7.0
85 - 120	53	27.8
50 - 85	90	46.5
20 - 50	36	18.7
	192	100

The lowest class (all land growing from 20 to 50 cubic feet of wood per acre per year) amounted to 18.7 percent of the commercial timberland acreage in the South in 1970. In addition to this 36 million acres there are 17.6 million acres in the South which are classified as "unproductive", meaning they are growing less than 20 cubic feet of wood per acre per year. Many of these acres are capable of higher productivity levels under more intensive management. These unproductive areas include many familiar names such as pinyon-juniper. chaparral, scrub oak, sand, Cross-Timbers, and just plain "brush fields". Unfortunately these areas are often placed in the "unproductive" category simply due to a lack of data. Even though the natural vegetation is growing less than 20 cubic feet of wood per acre per year, a more productive species under intensive management may produce 2 or 3 times more wood on the same acre.

Anderson and Guttenberg (1971) have estimated that 50 million acres in the South have the potential for conversion to pine plantation. This total includes 25 million acres of oak-hickory timber type and 25 million acres of oak-pine type. Virtually all of this area is growing less than 85 cubic feet of wood per acre per year and much of it less than 50 cubic feet per acre per year.

Increasing the productivity of these marginal sites can be accomplished by a number of methods. Conversion of the native vegetation to a more productive species is often the most efficient method. In addition, direct site treatments such as ripping compacted subsoil strata serve to improve water infiltration rates, increase root pentration, and reduce planting costs. Tubelings and other types of containerized seedlings may be required on droughty soils. In wet areas, bedding and ditching have often improved both survival and growth. Fertilizers and herbicides have also been successfully used on a wide variety of sites. Hybrids and exotic species have survived and produced more wood than the native vegetation of specific sites. Progeny

test results have indicated that certain clones and certain families perform better on marginal sites than other tested material. It seems evident that a careful site evaluation followed by intensive site treatments and management will permit many marginal forest sites to reach profitable productivity levels. The following section is an example of marginal site utilization in Oklahoma.

Marginal Forest Sites in Oklahoma

There are 4.8 million acres of commercial forest land in Oklahoma (Sternitzke and Van Sickle, 1968). About 93 percent of this total is growing less than 85 cubic feet of wood per acre per year, and 65 percent is growing less than 50 cubic feet per acre per year. In addition to this commercial forest acreage, the 6.2 million acres of the "Cross-Timbers" type in Oklahoma (Gray and Galloway, 1959) represents a natural resource with an undefined potential for commercial forestry operations. (The following description of the Cross-Timbers area is quoted from Gray and Galloway, 1959, pp. 29-31). "The Cross Timbers is a large wooded area of rolling to hilly sandstone uplands extending from the Kansas line to Texas. It is an area of scrubby timber in which old growth is more or less open and park-like. Cutting and burning have caused prolific sprouting of the post and blackjack oaks to form many brushy thickets. Since the large areas lie between the eastern and central prairies, they were dreaded by early travelers who had to cross the timber belt on foot or on horseback - hence the name Cross Timbers."

Unfortunately, volume and growth data are not available for these Cross-Timbers areas. The poor form and low stocking rates of the post and blackjack oaks produce stands which vary in growth from an estimated less than 10 cubic feet per acre per year to a maximum of 50 cubic feet per acre per year. The only marketable wood produced consists of firewood and occasional cross-ties.

Attempts to improve the productivity of these Cross-Timbers areas have included chemical, mechanical, and prescribed burning treatments to remove the native vegetation. In some areas these conversion treatments have been followed by seeding and fertilization for improved pasture, whereas, in other areas native grasses have been allowed to take over. These treatments are expensive, and not always economically justified in terms of cattle production. Short-rotation pine timber crops (for example: pulpwood, fence posts, or barn poles) may be an attractive land-use alternative for some landowners of Cross-Timbers land.

Due to the fact that the Cross-Timbers area is outside the natural range of pines, the native vegetation must be killed and pines established by planting or direct seeding. These efforts to establish pines in the past have often failed due to high planting costs, lack of adequate fire control, and unreliable soil moisture. The shallow, rocky soils prevent the use of planting machines and slowdown hand planting crews. When adequate stands of trees have been established, wildfires have often destroyed them. Direct-seeding trials designed to reduce the cost of establishment have frequently failed due to the limited moisture storage in these shallow soils. An additional factor which must be considered when direct-seeding is the absence of specific mycorrhizae in the soil.

The Study Area:

This study is located on a typical Cross-Timbers site, two miles east of Lamar, Oklahoma (Hughes County) on land owned by Sarkeys Foundation. This area lies on the western edge of the natural range of shortleaf pine (Pinus echinata), in the forest-prairie transition zone. The dominant vegetation on the study area consists of post oak (Quercus stellata), blackjack oak (Q. marilandica), and hickory (Carya species), with an understory of tree huckleberry (Vaccinium arboreum), winged elm (Ulmus alata), and persimmon (Diospyros virginiana). Small stands of shortleaf pine are growing near Lamar and Calvin on the South Canadian River and scattered individual pines are growing near the study area. The soils are of Hector and Hartsell series and are shallow, extremely rocky, and well eroded on slight to moderate slopes. Mean annual precipitation ranges from 38 to 40 inches.

PROCEDURES

The native vegetation was killed by a combined aerial spraying of herbicides (2 pounds of 2, 4, 5-T + ½ pound picloram per acre) and prescribed burning. In January 1973, 1974, and 1975, all plots to be planted that season were burned to reduce competing vegetation. The two pine species native to Oklahoma (loblolly pine and shortleaf pine) were hand planted and direct seeded in February of each year. Three exotic species: Pinus brutia (Turkey), Pinus pinaster (Spain, Portugal, France), and Pinus virginiana (Alabama: Kimberley-Clark seed orchard) were also hand planted on these same three dates. All treatments were replicated three times in each of the three planting years. Planting was designed at a 6 x 8 foot spacing while direct seeding was done at the rate of one pound per acre for loblolly and 3/4 of a pound per acre for shortleaf. All seed was stratified for 30 days and treated with arasan. All plots will be evaluated annually for survival, growth, form, and damage from insects, disease, or animals for a 20-year period.

RESULTS

The first and second year survival and growth of planted shortleaf, loblolly, and Virginia pine seedlings was excellent. The survival percentages of the individual species for the first year were as follows: loblolly 97, Virginia 88, and shortleaf 81 (Figure 1 and Table 2). The second year survival and growth for the same three species also appears to be very good although specific data cannot be included at this time. The height growth of many seedlings has been outstanding, with several loblolly and shortleaf seedlings taller than 26 inches at the end of the first growing season and several trees taller than 4 feet at the end of the second growing season.

The survial of planted brutia and pinaster seedlings has been disappointing (Table 2) as has the direct-seeded loblolly and shortleaf. It appears that the severe competition from grass and weeds following prescribed burning is responsible.

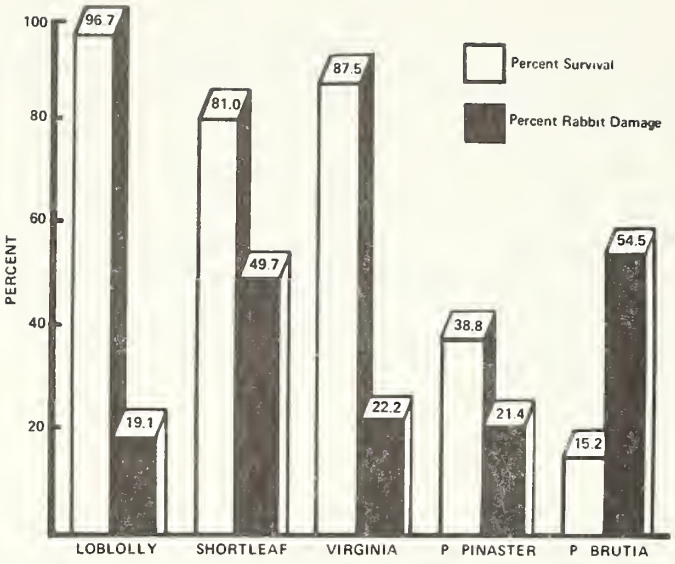

Figure 1. Survival and Rabbit Damage for Planted Seedlings

Table 2. First Year Survival, Growth, and Rabbit Damage of Planted Seedlings

	Shortleaf Pine	Loblolly Pine	Virginia Pine	Pinus Pinaster	Pinus Brutia
Survival (%)	81	97	88	39	15
Rabbit Damaged Seedlings (%)	49	19	22	21	54
Mean Height of Rabbit Damaged Seedlings (inches)	9.4	10.0	10.2	9.0	9.8
Mean Height of Undamaged Seedlings (inches)	16.0	17.1	17.7	12.9	16.5
Mean Height of all Combined	12.7	15.7	16.1	12.7	12.5

In this study, as in many other pine planting studies, rabbits frequently chewed on needles and buds and clipped the terminal shoots. Although the rabbits damaged 19 percent of the loblolly seedlings, 22 percent of the Virginia seedlings, and 49 percent of the shortleaf seedlings during the first growing season, very little mortality has resulted from this damage. (Notice the marked preferential feeding on the shortleaf seedlings in Table 2.) In most cases, the clipped seedlings have resprouted from new buds, resulting in only a minor growth loss. In addition, the second-year rabbit damage was considerably less severe than in the first year. The 1975 planting included a series of fenced seedlings in an effort to gain a more objective estimate of the rabbit damage.

Another local hazard was observed during the second growing season, when 25-30 of the tallest seedlings were killed by girdling from buck deer rubbing of antler velvet on the stems.

CONCLUSIONS

A successful forestry enterprise must produce a timber crop which can be sold at a profit. It is entirely possible that some of these trees will be fence posts or pulpwood size in 8 to 10 years. It is also possible that additional income may be available from grazing. At this time, an economic evaluation will be made comparing the establishment and management costs and the income produced.

At this time, it seems safe to say that loblolly, shortleaf, and Virginia pines, from the proper seed source, can be established on this site in adequate numbers. It should be recognized however that insect or animal damage and/or wildfires can destroy these seedlings at any time. In addition, a prolonged drought may reduce growth and possibly cause extensive mortality.

In conclusion, it is possible to establish pines on the Cross-Timbers area of Oklahoma during the years of adequate moisture. It is better to plant than to direct seed because of the greater growth and survival of planted trees during the first year. Loblolly, shortleaf, or Virginia pine can be recommended for planting. It is highly possible that landowners in the "Cross-Timbers" area of Oklahoma will have short rotation timber crops as an attractive land-use alternative in the very near future.

Other marginal sites throughout the South need to be evaluated for potential wood production. If only half of the 25 million acres of oak-hickory type could be brought into wood production averaging half a cord of wood per acre per year, this would yield 800 million cubic feet of wood per year. This is more wood than all of the roundwood harvested in the state of Georgia in 1970!

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ECONOMIC CASE FOR GENETIC MANIPULATION OF SHORT-ROTATION SYCAMORE

George F. Dutrow and Joseph R. Saucier

Abstract.--Best estimates of costs, yields, and revenues indicate that profits from short-rotation sycamore are highest on best sites, at wide spacings, and with 4- or 5- year cutting cycles. Genetically improved stock that provides a 10 percent increase in growth would almost double net revenues. Genetic improvement that would insure adequate growth without fertilization would allow marginal sites to become profitable.

Additional keywords: Sycamore yields, costs, simulation, genetic improvement, revenues.

Short-rotation sycamore seems assured of a future. The species responds to cultural treatments, grows rapidly to meet size and quality restrictions, and can be processed into a multitude of fiber-based products. Furthermore, modest genetic gains can enhance the economic potential of short-rotation sycamore. These gains can take either of two forms: (1) superior growth where fertilizer is applied, or (2) the best growth possible without fertilization. Economic comparisons between these options and standard short-rotation sycamore yields are summarized herein.

Researchers of the Southeastern Forest Experiment Station at Athens, Georgia have grown four crops (one seedling and three coppice) and measured the yields. These data provide a basis for setting requirements for economic feasibility of short-rotation sycamore plantations and for estimating gains from specific genetic improvements in planting stock.

COSTS

Formidable outlays are required to establish short-rotation sycamore plantations. These expenditures underscore the need for rapid developments of genetically superior planting stock.

Costs are categorized as fixed, variable, or annual depending on the nature of the expenditure and when it occurs. Site preparation is one of the major fixed costs. Practitioners recommend that sites be cleared, raked, burned, and disked prior to setting out sycamore seedlings or cuttings. Where site conversion is not necessary, preparation costs were estimated at $40 per acre by commercial organizations pilot-testing the concept. Where conversion costs are necessary, they were estimated at $35 per acre. For analysis, the combined cost of $75 per acre was charged to site preparation since most tracts have required conversion.

Fixed costs were also charged for weed control, fertilization, and a miscellaneous category. Weeds can be controlled either chemically or by cultivation and, in either case, current costs are $25 per acre. Energy crises and soaring chemical costs have inflated the price of chemical weed control and fertilization. The impact on net revenues may be eased by relying on weed control by cultivation and developing genetically superior

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Table 1

Estimated costs of establishing plantations of short-rotation sycamore - per acre

Cost Description	Spacing			
	1'x4'	2'x4'	4'x4'	6'x4'
	$ per acre			
A. Fixed Costs				
Site preparation (conversion = $35; clearing, burning, raking, and disking = $40)	75	75	75	75
Weed control (by chemicals or cultivation)	25	25	25	25
Fertilization	50	50	50	50
Miscellaneous (insect or disease treatment, trucking, management costs)	5	5	5	5
Total Fixed Costs	$ 155	$ 155	$ 155	$ 155
B. Variable Costs Per Thousand Seedlings*				
Seedlings 10/M				
Planting equipment 5/M				
Supervisory labor 7.70/M				
Total Variable Costs $22.70/M	$247.20	$123.60	$ 61.79	$ 41.20
C. Total Establishment Costs (fixed and variable)				
Without land purchase (A+B)	$402.20	$278.60	$216.79	$196.20
With land purchase at $300/acre	$702.20	$578.60	$516.79	$496.20
D. Periodic Costs	Occurrence		Amount	
Annual (taxes, fire protection, general management)	yearly		$ 2.00/acre	
Fertilization	each harvest		$ 50.00/acre	
Harvesting	each harvest		$ 0.75/ton	
Hauling	each harvest		$ 1.50/ton	

stock that promises adequate yields without fertilization. Miscellaneous fixed costs include general expenditures for insect control, trucking, and management efforts and are estimated at $5 per acre. Fixed costs are itemized in Table 1, with a total value of $155 per acre charged to the plantation regardless of site, spacing, or rotation length.

Planting stock or seedlings comprise a major proportion of variable costs which vary with spacing. Options simulated include 1X4, 2X4, 4X4, and 6X4, with seedling requirements ranging from 11,000 per acre for 1- by 4-foot spacing to 2,000 seedlings per acre for 4- by 6-foot spacing. Seedling costs were set at $10 per thousand. Planting-equipment costs of $5 per M seedlings and supervisory and labor costs of $7.70 per M also add to the variable costs. When the variable costs are summed to $22.70 per M seedlings, the importance of spacing as a factor in the financial outcome is obvious. Variable costs in the densest plantations amount to almost $250 (Table 1), well over half the establishment costs.

Combined harvesting and hauling costs are set at $2.25 per ton, Table 1, based on estimates provided by commercial experimenters and equipment manufacturers. With a conversion figure of 3 tons of whole-tree chips per cord, sycamore chips can be harvested and delivered to an industrial receiving point for $6.75 per cord, which compares favorably with costs of $15 per cord for bolts (Bellamy, 1974; Myers, 1973). Short-rotation sycamore stems can be clearcut by a machine comparable to a silage chopper. Harvesting, chipping, and blowing the chips into a tractor-drawn wagon or truck would be a single operation. The required technology and even prototype equipment exist.

A final cost entering the calculations was for reestablishment of rootstock to support new series of coppice crops. This item was assumed to equal the initial establishment costs minus conversion costs of $35 per acre.

PHYSICAL YIELDS

Yields from seedlings and three coppice crops have been established. Table 2 presents yields for short-rotation sycamore options that appear economic. Other cutting cycles (1 and 2 years) and closer spacings (1X4 and 2X4) were analyzed, but proved uneconomic for the yields, prices, and costs assumed.

Silvicultural precautions are prerequisite to achieving the listed yields. Foremost amongst critical factors is the selection of a site. Sycamore appears to grow best on well aerated, fertile, mildly acid to mildly alkaline soils with sufficient drainage but with some ground water in the root zone. Poorly drained coastal plain sites were found to severely inhibit growth, whereas similar, but well drained sites supported vigorous growth (Steinbeck, McAlpine, and May, 1972). Table 2 also stresses the critical effect of site on yields. Regardless of spacing and rotation length, yields, and resultant profitability varied substantially between "favorable" and "medium" sites. The key index was the proportions of sand, clay, and silt in the soil. Favorable sites had approximately 40 percent sand and were classified as sandy clay loam. Medium sites were about 25 percent sand and classified as silty clay.

Table 2

Physical yields of short-rotation sycamore - green weight

Plantation Management Options	Favorable Site	Medium Site
Case 1. Spacing: 4'x4'; Cutting cycle - 3 years		
Seedling yield at age 3	15.7 tons/acre	12.0 tons/acre
Coppice yields each 3 years	25.5 tons/acre	15.0 tons/acre
Total decline in productivity of stand by age 24 (7 coppice crops)	8 percent	8 percent
Case 2. Spacing: 4'x4'; Cutting cycle - 4 years		
Seedling yield at age 4	26.0 tons/acre	20.0 tons/acre
Coppice yields each 4 years	38.0 tons/acre	23.0 tons/acre
Total decline in productivity of stand by age 32 (7 coppice crops)	10 percent	10 percent
Case 3. Spacing: 4'x4'; Cutting cycle - 5 years		
Seedling yield at age 5	35.0 tons/acre	27.5 tons/acre
Coppice yields each 5 years	51.2 tons/acre	35.0 tons/acre
Total decline in productivity of stand by age 40 (7 coppice crops)	12 percent	12 percent
Case 4. Spacing: 6'x4'; Cutting cycle - 3 years		
Seedling yield at age 3	15.0 tons/acre	10.5 tons/acre
Coppice yields each 3 years	24.0 tons/acre	12.0 tons/acre
Total decline in productivity of stand by age 24 (7 coppice crops)	8 percent	8 percent
Case 5. Spacing: 6'x4'; Cutting cycle - 4 years		
Seedling yield at age 4	22.0 tons/acre	15.0 tons/acre
Coppice yields each 4 years	36.0 tons/acre	21.0 tons/acre
Total decline in productivity of stand by age 32 (7 coppice crops)	10 percent	10 percent
Case 6. Spacing: 6'x4'; Cutting cycle - 5 years		
Seedling yield at age 5	30.0 tons/acre	20.0 tons/acre
Coppice yields each 5 years	50.0 tons/acre	35.0 tons/acre
Total decline in productivity of stand by age 40 (7 coppice crops)	12 percent	12 percent

Achieving high plantation survival is difficult with many hardwoods, but this has not been the case with short-rotation rates near 90 percent (Steinbeck, et.al., 1972; Kennedy, 1974; Kormanik, et.al., 1973).

In the analysis, a gradual decline in productivity of rootstock was simulated. Decline rates were set at 8, 10, or 12 percent of yields for cutting cycles of 3, 4, or 5 years for a full production schedule of one seedling and seven coppice crops. For example, a full rotation of seedling and coppice crops on a 5-year cutting cycle would take 40 years. The final yield would be 12 percent less than the first to reflect declining capability of roots to support regrowth.

Established yields are subject to improvement by genetic manipulation of growing stock. Short rotations permit both rapid evaluation of genetically altered stock and adoption of improved planting material. For economic analysis, genetic improvement was assumed to have one of two possible effects: (1) a 10-percent increase in yields where fertilizer is applied, or (2) 80 percent of normal yields in the absence of fertilizer.

STUMPAGE AND DELIVERED PRICES

From the market value for chips, harvesting and hauling costs were deducted to derive stumpage prices as residuals. In 1973, bark free, green hardwood chips delivered to the mill were worth $10 per ton (Bellamy, 1974). It is unlikely that chips containing bark and possibly leaves would bring more than $7 or $8 per ton. Deducting harvest and hauling costs lowers stumpage to about $5 per ton, which was used as the base figure for most of the economic calculations and comparisons.

An imputed delivered price of $10 per ton was used for firms that might manage, harvest, and process sycamore chips from their own plantations. It was assumed that industry would consider short-rotation sycamore as an alternative to buying on the open market and as a means of minimizing unfavorable price fluctuations. If so, an internal price of $10 per ton would serve as an imputed opportunity cost for comparing forest management options. Industry would choose short-rotation sycamore if resultant present net worth or internal rates of return exceeded those derived from other means of supplying the mill with wood fiber.

As noted earlier, substantial costs are involved with establishing and managing short-rotation sycamore plantations. Offsetting these costs, however, are tangible advantages in harvesting and hauling. Labor requirements would be minimal for harvesting large volumes of sycamore on small areas by mechanical means. Further savings would accrue through the higher operating efficiency of harvesting equipment when large volumes of wood fiber would be gathered from compact cutting units. Harvesting and hauling sycamore chips appears to be less than half as costly as conventional pulpwood operations. For a conversion of 3 tons of chips per cord of wood, sycamore chips can be delivered for less than $7 per cord. Conventional harvest-and-haul costs currently range upward from $15.

PROCESSING AND UTILIZATION OF JUVENILE SYCAMORE

Recent technological innovations favor expanded markets for particle-based and reconstituted wood products. Tests have found sycamore chips suitable for production of linerboard, quality bond paper, newsprint, particleboard and hardboard, (Ga. Forest Research Council, 1973). Pulp produced from young sycamore trees had shorter cooking cycles and equal or superior strength characteristics. Quality improved with age of trees but even 2-year old sycamore produced material comparable to general mill results.

Processing advantages associated with sycamore include utilization of the entire tree-stems and branches including bark, but preferably not leaves. Furthermore, lower cooking pressures and temperatures suffice, and digester times are shorter than for conventional hardwoods. With closer utilization of wood fiber from every acre and research to expand production potentials, it is likely that uses for short-rotation sycamore and other juvenile woods will multiply.

Attention should be drawn, however, to processing shortcomings. With lower specific gravity, pulp yields per unit of wood fiber will be less so that given levels of production require greater procurement, transportation, and storage costs. Interestingly however, juvenile sycamore unlike many other species, for relatively high specific gravity and long fibers--approximately 80 to 90 percent of mature wood values (McGovern 1973; Saucier and Ike 1969).

ECONOMIC IMPLICATIONS

Costs, yields, and prices were combined in several options to calculate present net worth, internal rate of return, benefit-cost ratio, and equivalent annual income for sycamore investments. Results of analyses of standard yields are shown in Tables 3 and 4. Benefits from genetic gains are given in the text. Answers were sought to the following questions:

> How do different sites and cutting cycles affect profitability of short-rotation investments?
>
> Do different spacings significantly alter costs and revenues?

The full range of calculations, evaluations, and comparisons was made possible by the investment program MULTIPLOY developed by (Row, 1974).

Investment possibilities are presented in Table 3. Measurements common to each of the alternatives include stumpage prices of $5 per ton, one seedling and seven coppice crops with gradual decline in productivity, and a discount rate of 8 percent. Economic criteria tabulated include present net worth, equivalent annual income, benefit-cost ratios, and internal rates of returns. Each of these measures has advantages and drawbacks as a ranking device and each has its advocates and critics. All are included here to serve the needs of a wide audience. Yields depicted in Table 2 are combined with costs presented in Table 1 with revenues set at $5 per ton to measure investment potential of different management options.

Table 3

Economic implications - stumpage sales

Plantation management and investment opportunities	PNW [a] ($/acre)	EAI [b] ($/acre)	B/C [c] ($/$)	IROR [d] (%)
1. Favorable site; 4'x4' spacing; stumpage price: $5/ton				
3 year cutting cycle with 8 harvests	- 48.47	- 4.60	0.88	6
4 year cutting cycle with 8 harvests	45.45	3.97	1.12	10
5 year cutting cycle with 8 harvests	96.89	8.13	1.28	11
2. Medium site; 4'x4' spacing; stumpage price: $5/ton				
3 year cutting cycle with 8 harvests	-186.66	-17.73	0.54	00*
4 year cutting cycle with 8 harvests	-104.79	- 9.16	0.72	2
5 year cutting cycle with 8 harvests	- 31.68	- 2.66	0.91	7
3. Favorable site; 6'x4' spacing; stumpage price - $5/ton				
3 year cutting cycle with 8 harvests	- 48.46	- 4.60	0.88	5
4 year cutting cycle with 8 harvests	34.40	3.01	1.10	9
5 year cutting cycle with 8 harvests	92.79	7.78	1.28	11
4. Medium site; 6'x4' spacing; stumpage price = $5/ton				
3 year cutting cycle with 8 harvests	-207.24	-19.68	0.47	00*
4 year cutting cycle with 8 harvests	-119.46	-10.45	0.66	00*
5 year cutting cycle with 8 harvests	- 36.19	- 3.03	0.89	7

a. PNW = present net worth
b. EAI = equivalent annual income
c. B/C = benefit/cost
d. IROR - internal rate of return

* Negative rates of return; i.e., discounted costs exceed benefits at all rates of return

Table 4

Economic implications - sale at delivery point

Plantation management and investment opportunities	PNW[a] ($/acre)	EAI[b] ($/acre)	B/C[c] ($/$)	IROR[d] (%)
1. Favorable site; 4'x4' spacing; delivered price = $10/ton *				
3 year cutting cycle with 8 harvests	144.58	13.73	1.25	14
4 year cutting cycle with 8 harvests	268.10	23.45	1.47	16
5 year cutting cycle with 8 harvests	330.85	27.75	1.59	17
2. Medium site; 4'x4' spacing; delivered price = $10/ton				
3 year cutting cycle with 8 harvests	- 67.24	- 6.39	0.87	4
4 year cutting cycle with 8 harvests	38.38	3.36	1.08	10
5 year cutting cycle with 8 harvests	134.63	11.29	1.27	12
3. Favorable site; 6'x4' spacing; delivered price = $10/ton				
3 year cutting cycle with 8 harvests	133.61	12.69	1.24	14
4 year cutting cycle with 8 harvests	240.15	21.00	1.45	16
5 year cutting cycle with 8 harvests	313.51	26.29	1.60	17
4. Medium site; 6'x4' spacing; delivered price = $10/ton				
3 year cutting cycle with 8 harvests	-109.77	-10.43	0.77	00 **
4 year cutting cycle with 8 harvests	4.83	0.42	1.01	8
5 year cutting cycle with 8 harvests	116.50	9.77	1.25	12

a. PNW = present net worth
b. EAI = equivalent annual income
c. B/C = benefit/cost ratio
d. IROR = internal rate of return

* Sale at delivery point of $10/ton includes an additional cost of $2.25/ton for harvesting and hauling operations.

** Negative rates of return; i.e., discounted costs exceed benefits at all rates of return.

It is immediately obvious that the difference in yields between favorable and medium sites is critical when expressed in dollar terms. A landowner with medium sites anticipating a stumpage price of $5 per ton would use that land for some purpose other than short-rotation sycamore. Regardless of spacing or cutting cycle, medium sites don't pay. The bleak prospects pertain only to the landowner who hopes to grow sycamore on medium sites and profit from stumpage sales at $5 per ton. Industrial managers could conclude otherwise from different criteria of economic worth.

Favorable sites provide different prospects. Present net worths of nearly $100 per acre are likely for 5-year cutting cycles with 4X4 or 4X6 spacing. That is, an additional $96 or $92 per acre could be invested in short-rotation sycamore and the investment would still pay at an 8 percent discount rate. Or, as shown in the right-hand column, internal rates of return of 11 percent are anticipated; this value indicates the interest rate that equates all costs and revenues. For those who prefer other measures, 5-year cycles on favorable sites promise benefit cost ratios of almost 1.3 and equivalent annual incomes around $8 per acre.

Two other items important to investment analysis are shown in Table 3 and occur throughout the full range of options. First, returns increase with cutting cycle length. But, the gain from 4 to 5 years is less than from 3 to 4 years, which indicates that revenues are rising at a decreasing rate and that even longer cutting cycles are not necessarily recommended. This is especially true for 8 harvests with a 6-year cutting cycle which would be almost 50 years long with a high probability of declining rootstock and productivity. The other item shown in Table 3 is that returns, regardless of the criteria chosen, are greater with 4X4 spacing than 4X6 spacing. Thus, close spacing takes greater advantage of site potential than wide spacing.

Opportunities for industrial landowners, growing short-rotation sycamore to process in company facilities are outlined in Table 4. Significant changes in these data are a $10 per ton delivered price and an internal charge of $2.25 per ton for harvesting and hauling. The $10 price represents an opportunity cost for industry. The presumption is that industry can purchase chips as needed on the open market at $10 per ton. If the wood fiber can be grown on company lands, harvested, and hauled to delivery point for less than $10 per ton, it would be advisable to do so.

All economic criteria reflect a positive surge in Table 4. In fact, the present net worth of the investment on favorable sites with 5-year cutting cycles exceeds $300 per acre. In these cases, the company could buy land at $300 per acre to establish sycamore plantations. Where a choice exists, financial considerations dictate planting favorable sites to a 5-year cutting cycle. Even with the $10 price, 3-year cutting cycles promise financial loss on medium sites. Because of the substantial costs, which remain relatively constant regardless of cutting cycle, the higher yields and closer utilization of site potential of the longer cycles are required for economic optimization. Three-year cutting cycles were relatively unprofitable throughout the analyses, and the results of this option were deleted from most of the tables.

The economics of planting genetically improved planting stock that permits yields 10 percent above those listed as standard in Table 2 were assessed. With stumpage sales, medium sites remained marginal but present net worths improved substantially even though they remained negative. On good sites, the net worth for the 4-year cycle doubled and those for the 5-year cycle increased by 50 percent. For 80 percent of standard yields without fertilization, net worths on medium sites became positive for the 5-year cycle. Good-site yields were improved for both 4- and 5-year cycles. It would pay a company to invest its research and development dollars to develop planting stock that did not require fertilization.

CONCLUSIONS

Short-rotation sycamore promises industrial owners a profitable means of supplying a processing facility with wood fiber. Favorable sites and longer cutting cycles appear most advantageous, regardless of price, spacing, or number of crops obtained. Genetics research to increase yields would help speed adoption of short-rotation sycamore. Of especial importance is a genetically improved stock that would not require fertilization because it would greatly expand the supply of suitable acreage.

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SESSION II - BREEDING AND TESTING

MODERATOR: RAY E. GODDARD

ADVANCED GENERATION BREEDING

J.P. van Buijtenen [1/]

Abstract.--Advanced generation breeding is discussed in the framework of the overall breeding strategy, with emphasis on the key decisions which need to be made, rather than on specific solutions for a particular species. Factors that should be considered in the formulation of a strategy include the biology of the species, the choice of breeding methods, the use of combined or separate breeding and production populations, the manner in which the advanced generations are to be produced and the extent to which inbreeding is to be minimized. Key questions in the evaluation of a breeding strategy are the gain per cycle, the cost per cycle and the duration of a cycle.

Additional keywords: Breeding strategy, family selection, choice of testers, genetic gain, economic return.

INTRODUCTION

As the introductory paper for this session, its objectives are to set the stage and provide an organizational framework. Advanced generation breeding cannot be discussed separately from the overall breeding strategy, since it is the very heart of it. I will therefore discuss advanced generation breeding from the point of view of breeding strategy. In doing so my main purpose will be to pinpoint the questions which should be asked and answered for any specific case. A discussion more specifically oriented towards southern pines was presented by Franklin (1975).

WHAT FACTORS SHOULD BE CONSIDERED IN THE FORMULATION OF A BREEDING STRATEGY?

For our purposes a breeding strategy may be defined as an ingenious combination of breeding methods to achieve specific goals. These goals may not necessarily be the same for every breeding program. Some common goals are improvement in growth rate, wood quality, disease resistance, form, the preservation of germplasm, the formation of an adequate basis for long range improvement and the provision of an adequate raw material for a particular product, range of products or industry. The major factors which have to be considered in formulating a breeding strategy are the biology of the species, the choice of breeding methods, the use of combined or separate breeding and production populations, the manner in which the advanced generations are to be produced and the extent to which inbreeding is to be minimized. All these factors are related to each other and affect advanced generation breeding.

Biology of the Species

The biology of the species can present some unique opportunities or pose

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some serious limitations.

Some of the major considerations are (1) is the species monoecious or dioecious? (2) is the species wind pollinated or insect pollinated? (3) can the species be readily propagated vegetatively either by grafting or rooting? (4) at what age does the species flower? (5) can the species be effectively propagated by means of controlled pollination? (6) what is the production of viable seed in terms of the yield from one cross and from one tree? (7) how much variation is present in the species? (8) is the genetic variation in the desirable traits largely additive or does a substantial amount of non-additive variance exist? (9) does the species possess the genes for the desired trait or is interspecific hybridization desired? (10) can the species be grown in plantations? (11) how long does it take to test for the desired properties?

Other factors may play an important role as well, but the factors listed above are the most common ones that have a bearing on the choice of breeding methods employed.

What Breeding Method is most Suitable?

The choice of breeding method is strongly influenced by the biology of the species and in turn determines the direction the advanced generation breeding will take. Following are some of the breeding methods most frequently used.

A. Clonal propagation. Clonal propagation has two different possible roles in a tree improvement program: (1) the establishment of seed orchards or scion banks for the production of seed for breeding purposes or for commercial production, (2) the establishment of plantations for the commercial production of wood.

In the latter case clonal propagation is a breeding method while in the former it is merely a means of producing seed in larger quantities. Clonal selection and propagation can produce extremely large gains as has been demonstrated particularly with cottonwood. To attain further genetic gains however, it will be necessary to cross the selected clones among each other to establish a new breeding population in which further clonal selections can be made. Taking the long range view therefore, the clonal method will always have to be used in conjunction with other breeding methods.

B. Selection. Selection is most suitable in those instances where substantial amounts of additive genetic variation are present. Selection can take the form of individual tree selection, family selection, or combined selection. Individual tree selection is most advantageous when heritabilities are relatively high. In contrast family selection is more effective when heritabilities are low. Combined selection is always as good or better than the other methods, but the difference is never very great (Falconer, 1960). For the great majority of tree species this is a method that appears to be very suitable and is therefore chosen by many tree breeders.

C. Hybridization. Hybridization could take several forms, three of which

offhand appear potentially important in forest trees. If the species can be self-pollinated readily, one could develop hybrids between inbred lines much as has been done in corn. This method does not seem very useful in forest tree breeding now, but could become more important as more advanced generations are produced.

Secondly, hybridization could take the form of crosses among widely separated geographic seed sources. Namkoong (1974) has some rather interesting ideas on this. Local races do not always appear to be optimal for use as commercial forest trees. Instead there appears to exist an optimal environment where the best races occur for introduction to a certain area. Plotting the results of geographic seed source tests against climatic variables at the source, one may find that the optimum environment does not exist. In such a case a suitable combination of sources might produce a hybrid, which in a sense could be considered the result of a synthetic optimal environment. A study by Woessner (1972) has shown that such an approach might have promise.

Interspecific hybridization might be useful in a number of cases. Perhaps the greatest application might be the introduction of disease resistance. The occurrence of true hybrid vigor is less common although frequent enough to be of real interest (Fielding, 1962). For the production of improved wood properties the method does not appear to hold much promise (van Buijtenen, 1970).

All forms of hybridization need to be combined with some form of selection and the maintenance of separate breeding populations if the process is to be continued for more than one generation. It will necessarily be a rather complicated system, but may have great merit especially in the case of resistance breeding.

D. Polyploidy. This method has been applied successfully to improve quaking aspen (Einspahr, 1972). Faster growth, greater fiber length and increased wood specific gravity have been the primary responses to increasing the chromosome number. For long range improvement however, it needs to be combined with selection or hybridization to maintain further gains. In the case of triploids this would mean maintaining and improving diploid and tetraploid populations for the production of triploids by crossing. The triploids then can be propagated vegetatively for mass production.

Are the Breeding and Production Populations the Same or Separate?

Namkoong (1974) examined this question and concluded that either approach can be appropriate. Maintaining separate breeding and production populations would necessarily entail extra cost and it would therefore be necessary to point to advantages otherwise not obtainable to justify this cost.

A strong argument for separating the two populations is to avoid the conflict between increasing genetic gain by increasing the selection differential (i.e., by selecting a very small number of trees) and maintaining an adequate genetic base for future breeding. By separating the two populations it is possible to maintain a broad base in the breeding population and yet get a greater gain by only using the very top families for the commercial production

of improved seed or clonally propagated material. This is a key point that is often overlooked. Without a broadbased breeding population severe losses of germplasm can be expected.

A second argument for separating the breeding population from the production population is the effect of inbreeding. Exaggerating somewhat, one can say that no inbreeding can be tolerated in the improved seed harvested from the production population (the operational seed orchard), since any loss of vigor necessarily means a financial loss. In the breeding population on the other hand, inbreeding can be tolerated and actually may be desirable.

Production of Advanced Generations

The advanced generation population may serve many purposes (Burley, 1972; Andersson, 1960) such as: (1) evaluation of families for the purpose of roguing a seed orchard, or establishing a new orchard from the best clones; (2) providing the population for selection of the next generation; (3) providing estimates of genetic parameters such as additive and non-additive genetic variation, heritabilities and gain prediction; (4) demonstration of realized gain; (5) production of commercial end product.

Although separate tests could be set up for each objective, limitations on cost and manpower generally require that the tests are combined in some way. Preferably one test should serve all purposes.

The number of selections to be made is a critical decision. By using a small number of highly selected individuals, it is possible to make the greatest genetic gains. On the other hand it is also desirable to have a large population size to avoid losing too many genes from the population, which would limit the potential for future progress. Some compromise is called for. Twenty selections to establish a breeding population appears to be the absolute minimum. Approximately 1000 is the maximum attempted so far by a single industry or state organization.

An important point to be made is that the progeny test population does not need to be the same as the population in which advanced generation selections are made. As a matter of fact, a tester scheme of progeny testing is most effective when the worst possible parents are used as testers (Allison and Curnow, 1966). We therefore have potentially three distinct groups of trees to work with (1) the progeny tests (2) the breeding population - i.e., the plantation from which the new selections will be made and (3) the production population - i.e., the seed orchard. Following is a summary of some of the most common breeding systems.

A. Mass Selection. Allow the selections to mate at random, use all seed commercially and consider the entire production of seedlings as the next population. Although this system is simple, random sampling variations will cause some families to be overrepresented and others to be completely omitted, thus leading to a higher risk of inbreeding and loss of favorable genes.

B. Single Pair Mating Schemes. Different systems have been reviewed by

Namkoong (1974), Cockerham (1970) and Kimura and Crow (1963). There appears to be an inverse relationship between the early avoidance of inbreeding and eventual inbreeding reached after many generations of following the same mating scheme. In an initial population of N individuals inbreeding can be avoided for k generations if $N = 2^k$. Thereafter inbreeding increases rapidly. Systems studied include maximum avoidance of inbreeding, circular matings, and circular pair matings. The circular mating systems will develop inbreeding sooner (for N = 8 after 2 generations) but will lead to lower inbreeding levels in the long run.

C. Multiple Crosses Among Parents. Crossing patterns which have been advocated include (1) a factorial mating design such as a four tester scheme in which all clones are tested with the same four tester clones. This will quickly lead to high levels of inbreeding. (2) A complete diallel or modified half diallel. The complete diallel would include all the possible crosses including reciprocals and selfs. The modified half diallel would omit the reciprocal crosses and the selfs. This would of course give the maximum amount of flexibility, but would also be the most costly. Especially in the case where many clones are involved, the number of controlled crosses needed would quickly get out of hand. Some organizations use a modified half diallel among the best parents (as proved by open pollinated tests) to produce the next breeding generation (Stonecypher, 1968). (3) A series of disconnected small diallels (Anon, 1973). This is also a very flexible system and fairly easy to handle in practice since each diallel can be handled separately. For the purpose of using the information for testing it may be somewhat at a disadvantage since parents involved in different diallels cannot be compared very accurately. (4) Other partial diallel schemes can also be used (Anon, 1972). These allow considerable flexibility but have some practical disadvantages in that it will be virtually impossible to complete the whole crossing scheme in a short time span. Consequently the crosses will have to be separated into different sets to be planted out at different times. This argument of course holds also for the tester schemes. Many of these crossing schemes allow the possibility of making alternate sets of single pair matings, so that one can take advantage of family selection in addition to individual tree selection. In such a case some families will be eliminated and the rate of increase of inbreeding will be greater.

HOW TO EVALUATE A BREEDING STRATEGY

To effectively evaluate a breeding strategy, it's necessary to simplify the evaluation by dividing the strategy into separate portions. One very natural portion to look at separately is the selection of the parental population, in other words the initial step of the breeding program. This phase is followed by the recurrent or recycling portion consisting of the advanced generations.

Since the advanced generations are really the crucial part of the long range breeding program, it's advantageous to look at them first. Following are a number of questions that should be asked:

(1) what is the gain per cycle?
(2) what is the duration of one cycle?

(3) what is the cost of one cycle?
(4) what is the gain per year?
(5) what is the cost per year?
(6) what is the cost per unit gain?

For a given breeding scheme the cost per unit of gain will increase as the gain per cycle increases. This is so because the number of acceptable selections drops very rapidly as the selection intensity is increased. As a result the cost increases much more rapidly than the amount of genetic improvement obtained. This is nothing unusual and is to economists just another example of the law of diminishing returns. On the other hand, the cost of different breeding methods varies considerably and some are much more efficient than others.

The largest difference occurs between individual tree selection schemes and family selection schemes. Since we're generally dealing with characteristics of low heritability, the gain obtainable by individual tree selection is generally rather limited, perhaps about 10%. On the other hand, it is relatively cheap. Nevertheless, by the time that the 10% gain is reached you have arrived at the steep portion of the curve and additional gains become prohibitively expensive. Family selection is inherently much more expensive than individual tree selection but greater gains are possible. With the southern pines gains of 25 to 50 percent are obtainable with family selection.

After having made a decision on what kind of a breeding scheme to adopt for the recurrent portion, it is time to look back at the initial phase of selecting the parental population. The two main questions here are:

(1) what is the gain obtained in this portion of the selection scheme and
(2) how well does it lead up to the recycling portion.

EXAMPLE OF AN ADVANCED GENERATION BREEDING SCHEME

To illustrate these considerations it is perhaps useful to give a concrete example. The species considered is Hypoplatanus obtusa vB. [2/] This particular example was chosen because it is fairly complex and shows the application of some ideas that so far have not regularly been incorporated into advanced breeding plans.

Biology of the Species

Hypoplatanus obtusa is an understory species growing under sycamore stands. It has a very dense wood and produces a fiber highly suitable for pulping. It can be grown on a coppice rotation of three years. Without any genetic improvement, it is capable of producing four tons of dry fiber per acre per year. The species is dioecious and flowers at age 3. The female flower can be readily hand pollinated and produces between 200 and 400 seeds per flower. The seeds are rather small and germinate readily with careful

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[2/] This is a very rare and as yet undiscovered species. Any resemblance with sycamore is purely coincidental.

treatment. One hundred sound seeds ordinarily are expected to yield about 50 plantable seedlings.

The species can be readily propagated from rooted cuttings by planting 8-inch cuttings in nursery beds about mid-February before they leaf out. The species has a rather thin bark and can be harvested as a whole tree without unduly adverse effects on pulp quality.

The Breeding Cycle

The advanced generation breeding cycle consists of a ten-year cycle (table 1). In year one of the cycle, the selections are made in the advanced generation population. At that time, clonal tests are established of these selections and a small clonal orchard is established from rooted cuttings.

Table 1. Advanced generation breeding cycle of Hypoplatanus obtusa

Year	Breeding Population	Test Population	Production Population
1	Selections in F_n Generation	Establish Clonal Lines of Selections	
2		Cross Selections with Polymix of Worst Trees	
3			Establish Unrogued Seed Orchard
4		Field Plant Progeny Test	
5		Field Plant Clonal Test	
6	Make Single Pair Matings of Best Selections	Evaluate Progeny Test	
7		Evaluate Clonal Test	Rogue Orchard or Start New Orchard
8	Field Plant Seedlings		
9			Produce 10 Best Clones Commercially
11	---------- START NEW CYCLE ----------		

Since the species produces abundant seed, this will produce all the seed that will be required. A number of crosses are made for the purpose of progeny

testing by pollinating the selections with a mixture of pollens from the worst trees available. In the following year, seed is collected and in year four a progeny test is established. The progeny test is evaluated after two years in the field and single pair matings are made among the parents of the best families to produce the following generation of the breeding population. These are field planted in year 7. At year 7 the clonal orchard can be rogued to the best clones and at age 9 of the cycle, rooted cuttings of the ten best clones can be mass produced for commercial planting purposes. In year 11 new selections are made in the breeding population, which constitutes the beginning of the next cycle.

Expected Gains and Economic Considerations

Based on the admittedly rather limited experience with this species gains were calculated for the three different production populations: the unrogued seed orchard, the rogued seed orchard and the rooted cutting nursery. These are alternatives and would not necessarily all have to be done. For this reason it is important to look both at the gains possible and the economics.

In the calculations it was assumed that in year one of the breeding cycle, one hundred initial selections were made. These would be the ten best trees of each of the ten families formed by single pair matings among the best 20 selections of the previous generation. Two hundred trees per family are raised every generation.

A summary of the comparisons is given in Table 2. The unrogued seed orchard would produce a gain of only 5%. This would be obtained as a result of individual tree selection within the families. The total cost discounted to the beginning of the breeding cycle at 8% interest would be $17,700.

Table 2. Cost and economic returns for the three kinds of production populations of Hypoplatanus obtusa

Year	Production Population	Gain %	Total Cost,$	Cost/acre of Plantation,$	Cost/ton of Fiber,$
3	Seed Orchard	5	17700	23	5
7	Rogued Seed Orchard	20	14700	24	5
9	Rooted Cuttings	40	28600	40	4.30

Assuming that the coppice plantations are established with 5000 plants per acre, the cost per acre for tree improvement will be $23. It is assumed further that these coppice stands will be harvested every three years and will be cleared and replanted to improved stock after 3 rotations. On this basis the cost per ton of fiber obtained as a result of genetic improvement will be $5. In other words this is the "marginal" cost necessary to produce an additional ton of fiber with genetic improvement over and above the basic cost of growing the 4 tons annually from unimproved stock.

The rogued seed orchard will be established at age 7 and the gain will

be 20%. Total cost will be $14,700 and the cost per acre $24. The cost per ton of fiber due to genetic improvement will again be about $5. Although the genetic gain has been increased the economics are unchanged because of the delay of four years in obtaining this gain.

The rooted cuttings will produce a gain of 40%. The total cost will be $28,600, and the cost per acre of improved planting is $40. Despite the further delay in availability, the cost per ton of fiber due to genetic improvement is reduced to $4.30 because of the substantial increase in genetic gain.

Comparing these three alternatives the rooted cuttings would appear to be the best choice. The reason for this is not only the somewhat lesser cost per ton of fiber but also the fact that the additional gain will be available about 8 years sooner than otherwise would be the case. This is so because during the following cycle the seed from a rogued seed orchard would be equal in quality with the rooted cuttings of the previous cycle assuming the genetic progress remains constant from one generation to the next.

CONCLUSIONS

The above example was merely used to illustrate the principles involved in developing and evaluating a strategy for advanced generation breeding.

The most important ingredient in developing such a strategy for a new species is an open mind willing to explore the unique opportunities the species offers rather than following conventional procedures.

The most crucial decisions are the choice of breeding method and whether the breeding plantation, the progeny test plantation and the plantation producing the seed (or rooted cuttings) are kept separate or are combined in some way.

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MANAGING GENETIC RESOURCES FOR THE FUTURE
A PLAN FOR THE N. C. STATE INDUSTRY COOPERATIVE TREE IMPROVEMENT PROGRAM

Robert J. Weir and Bruce J. Zobel[1/]

Abstract.--Plans have been developed to manage the genetic resources of the N. C. State Cooperative Program for future generations of improvement. The program will be developed with three major phases: (1) Breeding good general combiners, (2) a continuation of the main line program through breeding of second-generation selections, and (3) selection and breeding of trees from unimproved plantations. A regional program concept will be used in the development of the three phases. Within each broadly defined region, five to 10 member organizations will pool genetic resources and share in the breeding and testing work.

Additional keywords: Pinus taeda, tree breeding, selection intensity, coancestry, genetic base, genetic gain.

INTRODUCTION

The North Carolina State University-Industry Cooperative Pine Tree Improvement Program is extensive, with emphasis on improvement through applied genetics. Seed orchards of loblolly pine (Pinus taeda L.) developed from the first cycle of mass selection are currently producing seed for 150 million plantation seedlings annually. Within the next few years these orchards will yield sufficient seed to regenerate more than 400,000 acres per year with 10-20 percent gain in volume over unimproved stock. Improvements in tree and wood quality and disease resistance will be at least of equal magnitude and value. The N. C. State program has captured only a portion of the improvement possible; ample genetic variation remains for additional cycles of improvement.

Ideally, choices among alternative breeding and testing strategies should be based on long-range (many generations) economic comparisons of net returns with respect to breeding and production costs and returns. However, information is only now becoming available to allow meaningful economic evaluations of first-generation improvement efforts (Porterfield, 1973). Detailed economic comparisons of future alternatives would be very speculative. It seems more appropriate to consider within the current program an improvement schedule which maximizes genetic gain in the near future with appropriate opportunities for subsequent cycles of improvement. The improvement strategy proposed is rather specific to the biological and economic resources within the N. C. State Cooperative Program. Therefore only certain aspects of the plans discussed here will have general application to other programs.

A REGIONAL PROGRAM CONCEPT

The North Carolina State Tree Improvement Program was developed as a cooperative. The 26 industrial and three state members have worked as a team freely exchanging

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research results and plant resources. The area of operation includes the range of loblolly pine east of the Mississippi River. Within this area over 45 individual improvement programs with 170 seed orchards have been developed for loblolly pine alone.

Breeding and testing programs have been developed for each member, while the production phase (commercial seed orchards) includes a concerted effort to pool the best of the available plant material within any given geographic area. Good examples of such resource pooling are the 1.5 or improved first-generation production seed orchards. If satisfactory gains are to be obtained in the future it will be necessary to work regionally in the breeding, testing and production programs. No organization has the plant resources available to undertake recurrent selection and improvement independently for advanced generations. Now, as never before, the reliance of each member organization on the regional resource base provided within the cooperative is apparent. Within each broadly defined region from 5 to 10 distinct loblolly pine improvement programs exist that will contribute plant resources to a given regional pool.

Regions are broadly defined by physiographic and environmental conditions. Specific genotypes will generally be utilized only within the region from which they originate, but tests are now underway (wide testing of good general combiners) that will reveal their performance outside their region of origin. The concern over movement of trees into differing environments is that genotype - environment interaction may reduce genetic gain.

It can be seen from figure 1 that regions as defined are not entirely distinct. Overlapping is encountered as a direct consequence of gradations in environmental influences and suitable genotypes will be judiciously moved across regional boundaries. Until research results indicate otherwise such movement will be done only when shortages of plant resources within a region make it mandatory for a broadening of the genetic base; extreme caution will be used when any major moves are to be made.

THE COOPERATIVES FUTURE STRATEGY - A SCHEDULE

A balanced breeding and production program for advanced generation loblolly pine improvement can be realized through the development of three distinct resource bases. They are: (1) good general combiners, (2) second-generation selections from the main line program, and (3) new plantation selections. These three avenues of current and/or future emphasis are justified on the basis of expected genetic gain, timeliness of the anticipated gain and the operational feasability of development. An important additional consideration is the maintenance of a broad genetic base for future cycles of improvement.

Each of the three avenues of improvement are to be developed within each of the regions described. Scheduling in the western regions of the Cooperative will vary from the others because of later initial program development. However, if the breeding, selection and orchard establishment is expedited without delay the planned production orchard establishment schedule (see table 1) can be followed.

Figure 1. Generalized Regional Program Boundaries - broken lines designate boundaries with major overlap.

1. Northern Coastal Region - Encompassing Virginia and much of North Carolina.

2. Mid-Coastal Region - Encompassing southern N. Carolina and northern S. Carolina.

3. South Coastal Region - Encompassing Coastal areas of southern South Carolina, Georgia and northern Florida.

4. Gulf Coastal Region - Ranging from the southern Georgia Coastal Plain West along the gulf to the Mississippi River.

5. Upper Coastal - Western Piedmont Region - Encompassing the upper Coastal and central Piedmont regions of Mississippi, Alabama and Georgia.

6. Eastern Piedmont Region - Ranging Northeast through the Piedmont from Georgia to Virginia.

7. High Piedmont Region - Including Tennessee, northern Mississippi, Alabama and Georgia.

8. Outlier Areas in Florida and the Eastern Shore - It is expected that test results will confirm these areas can be combined with adjacent regions.

Table 1. A schedule of production seed orchard establishment through successive generations of improvement.

Production Orchards	Establishment Period
1st generation	1960[1/] - 1970
1.5 generation (improved first)	1969 - 1978
2nd generation	1976 - 1984
Improved 2nd generation	1986 - 1990
3rd generation	1990 - 1998

With the exception of 1.5 generation orchards, which are established with tested clones, all orchards will be subject to upgrading by roguing following testing. It is evident that establishment and production phases of the different stage orchards will be overlapping. An organization may have at any given time as many as three orchards under management or development, e. g., a first-generation rogued orchard in full production, a 1.5-generation orchard starting to produce and a second-generation orchard under initial establishment. As newer and genetically better orchards begin production older orchards will be phased out.

The three lines of development will serve as the foundation for ongoing production orchard programs. The breeding schedule is schematically outlined in figure 2.

Phase One - Good General Combiners

Good general combiners are first-generation parents that have consistently produced outstanding progeny, as determined from progeny tests. In any given orchard of 25 to 35 clones, as many as 3 to 5 good general combiners have been identified. Improved first-generation seed orchards (1.5 generation) are developed by establishing the good general combiners from each of five to 10 programs within a region into a single orchard. Generally the 1.5-generation orchard clones are selected on the basis of multiple trait superiority. On occasion, specialty orchards have been developed with major emphasis on a single trait such as disease resistance.

At age 8, it appears the progeny from 1.5-generation orchards will produce 25% greater volume than unimproved plantations. This improvement will be 15% greater than gain commonly observed from unrogued first-generation orchards, primarily as a result of increased selection intensity and selection on family performance. Additional breeding and subsequent selection among the progeny of these outstanding clones is expected to result in "super" second-generation orchards with gains on the order of 50% increased volume over unimproved stock. To attain this goal the following program development schedule is planned:

a.	Breeding the general combiners and testing their progeny	1975 - 1983
b.	Improved second-generation orchard establishment	1985 - 1990

The improvement to be derived from developing the good general combiner population is considerable while the additional investment required is minimal.

1/ The initial date in any given period indicates when the first significant orchard acreage has been, or will be established.

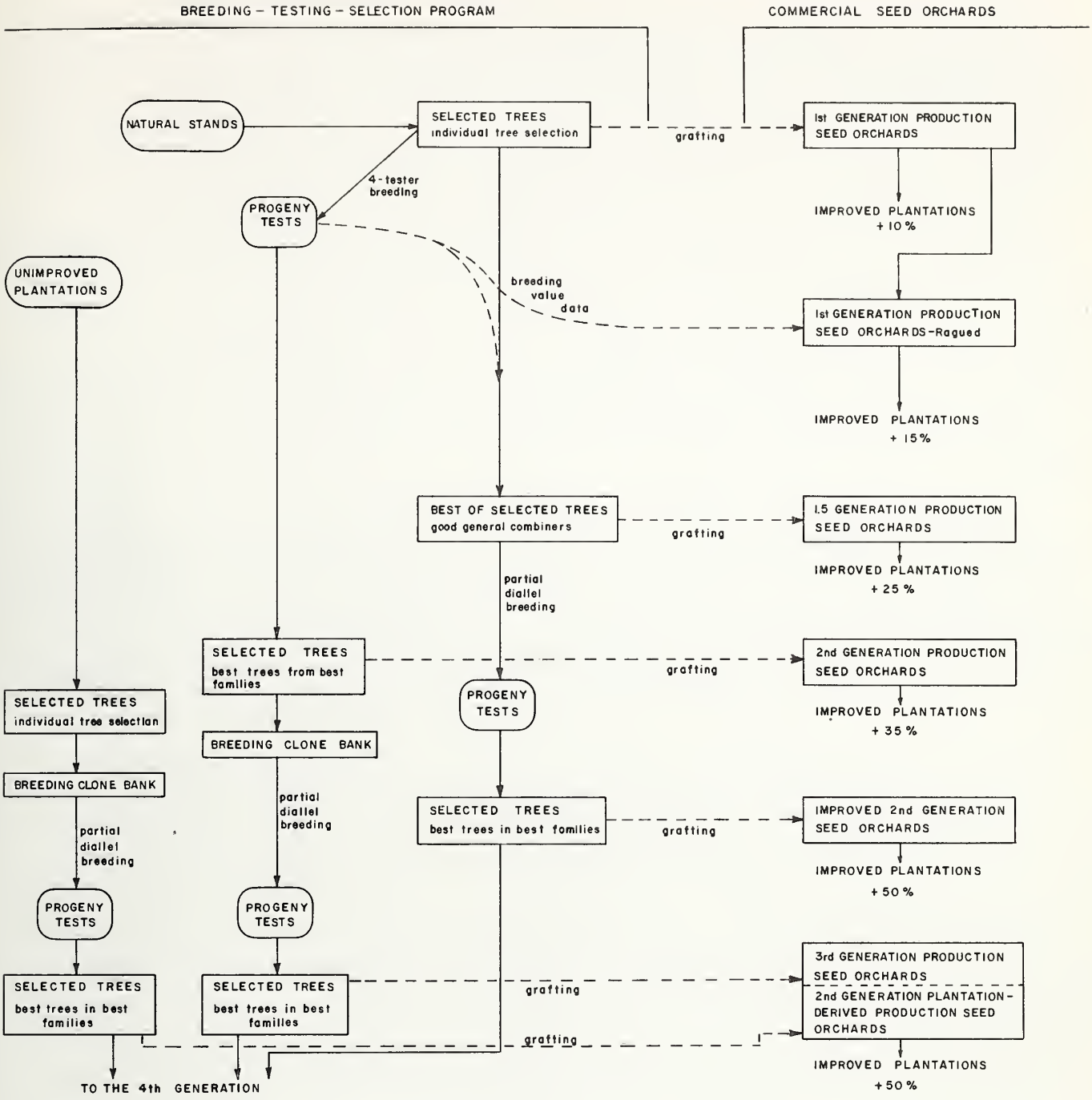

Fig. 2. Flow chart showing some short-term and long-term activities for the Cooperative; these consist of two basic activities:

1. Maximum, immediate utilization of the best plant material already developed
2. Development of a sound, broad genetic base through a long-term selection and breeding program

Good general combiners will be mated in a partial diallel scheme with each clone mated to at least 8 others. Because of the varied number of clones pooled from different programs within each region, it will be impossible to maintain balance in the partial diallel. The objective is to quickly generate a population from known good genotypes in which to select. Crossing will usually be among clones from different orchards, the pollen to be provided from the N. C. State pollen bank.[1/] The number of crosses required from each member will vary from 8 to 12 for each orchard.

Because of the rapid increase of relatedness among families (coancestry) the good general combiner breeding program is expected to terminate as a breeding line with the completion of improved second-generation orchards. Only a few outstanding lines will be carried forward as a part of the continuing recurrent selection program. Some crossing among good general combiners from widely separated regions will be done, but their uncertain potential dictates minimal emphasis until the value of the wide crosses is known. Results from wide testing of good general combiner progeny and a wide crossing program will be available within a few years.

Phase Two - The Main Line Program

Each member organization selected from 25 to 35 first-generation parent trees from natural stands. These were progeny tested using a 4-tester (or 5-tester) factorial mating scheme which provided information necessary to rogue the seed orchards and to identify the best general combiners. The progeny tests also serve as a population base for second-generation selection. The very best of the second-generation selections are established in production seed orchards while all are included in clone banks to be subsequently mated to create a base population for a third cycle of selection. The schedule for this main-line phase is as follows:

a.	First-generation seed orchards	1960 - 1970
b.	Breeding and testing first generation-selections	1967 - 1977
c.	Second-generation orchard establishment	1974 - 1980
d.	Breeding and testing second-generation selections	1980 - 1988
e.	Third-generation orchard establishment	1990 - 1998

The second-generation production orchard is comprised of the best of the total second-generation select population. Since maximum genetic gain is the objective, the trees established in the orchard are selected as intensively as possible. An additional constraint on the use of second-generation selections in the production orchard is that many are related, being half-sibs or full-sibs, thus the chance of inbreeding is introduced. To use second-generation selections with no regard for the likelihood of related matings would jeopardize the genetic improvement, thus related selections are used only when they can be spatially separated in the orchard. A 90' spacial separation is minimal according to studies by McElIwee (1970).

Diversity must be retained in the breeding population because it is the base of genetic variation for the third generation. Each member organization will obtain approximately 100 second-generation trees per orchard program for inclusion in their breeding clone bank. Therefore, 500 to 1000 second-generation selections will be retained within each regional program. Although such a large number of selections seems impressive, the utility of this population as a breeding base is deceiving

1/ The pollen bank provides for long-term storage of pollen from good general combiners in a central location. Pollens will be distributed as needed in the breeding program.

because of extensive coancestry. The amount of relatedness results directly from the use of the tester mating design; a maximum of only 4 or 5 unrelated selections per orchard or 20 to 50 unrelated selections per region are available, depending on the number of programs within the region. With complete outcrossing the third-generation base population for any given region can have no more than 10 to 25 completely unrelated families.

With the above limitation, two conclusions are: (1) The base populations to be developed for third-generation regional programs, even though large in numbers, will provide limited utility by themselves because of the coancestry. A broadening of genetic base is essential. (2) A very large investment in this phase of the breeding program does not appear justified.

The base populations can be enlarged in a number of ways: (1) If the wide testing of good general combiners indicates good adaptability the operational region size will be increased with the number of useable selections within any region becoming greater. (2) If inbreeding tests show only a moderate depression from low levels of inbreeding, the breeding population could then be enlarged in proportion to the number of related matings allowable in the production seed orchards. The genetic base would be broadened by making available more genotypes per region. (3) If "heterotic" effects result from wide crossing with little concurrent reduction of additive genetic variance, breeding and selection with widely separate genotypes would be justifiable. Such a wide cross program could be useful with good general combiners and second-generation selections. (4) A direct procedure for broadening the base involves selection and breeding of new genotypes with the subsequent incorporation of useful individuals into the third-generation base population. Such a program to expand genotypes is to be implemented by selection and breeding plantation trees. (see following section - phase three).

Second-generation selections from female parents with outstanding good general combining ability will be bred in the synthesis of the third-generation base population. Progeny from the best three to five general combiners per orchard will constitute the breeding population. By contrast, little if any selection on the male side of the pedigree (selection among the testers) is judged desirable. With few testers from which selection can be made, gains will be minimal, while increased coancestry would be significant. Only selections having extremely poor male parents will be eliminated; it appears that progeny from three of the four or five male testers are good enough to be included in the breeding program. Thus each orchard program will contribute selections from 12 full-sib families to the regional breeding population. A regional breeding population will be comprised of several full-sib selections from each of 60 to 120 full-sib families. Only occasionally will extremely superior individuals from poor families be included in the breeding program. Use of a combined selection index will enchance identification and the likelihood of success from breeding such unusual individuals.

Control of potentially deleterious inbreeding in advanced-generation production orchards can only be achieved if complete pedigree information is available (Zobel et. al. 1972, Weir 1972). Therefore, specific mating will be continued in the breeding program with second-generation selections. However, unlike previous breeding efforts, many sets of full-sib individuals will be included in this breeding population. The individual members of a full-sib set can be pooled without any loss of vital pedigree information. Pooling full-sibs into a single breeding entity will

confound the variation among full-sib and cousin progeny in what is commonly referred to as "within family" variation. While this and other similar confounding makes estimation of genetic components of variance and subsequently genetic gain rather complex, it does not restrict the genetic variation open to selection nor does it contribute to any nonidentifiable increase in coancestry. Pooling full-sibs into a single breeding entity will reduce costs for this phase of the breeding and testing program. Because of the expected limitation on utility of the resulting population such a reduction is appropriate.

Each of 60 to 120 full-sib sets are to be bred to six others in a partial diallel scheme. To complete such a program, 180 to 360 total crosses will be required within a region. The five to 10 member organizations of a region will each be required to complete about 36 crosses. This workload is commensurate with the utility of the population to be derived. Because of the difficulty in comparing performance within a population having a mixture of inbred and outbred individuals, all breeding work will be restricted to crossing among unrelated individuals.

For production purposes, third-generation selections from the main-line program are to be combined with second-generation selections derived from the plantation selection and breeding (to be described in the next section--phase three). Estimates of genetic gain expected from these combination seed orchards do not substantially differ from those for improved second-generation orchards. The fact is these combination orchards may never be established. However, the investment in breeding these resources is required so that improvement beyond the maximum shown (figure 2) can be realized. Without breeding main-line second-generation selections and/or plantation selections, additional genetic gains in the fourth generation will not be possible.

Phase 3 - Plantation Selection and Breeding

Coincidental with development of third-generation production seed orchard programs is the need to broaden the genetic base. In the South many thousands of acres of genetically unimproved loblolly plantations exist that constitute a most valuable gene pool yet to be exploited. An extensive selection and breeding program with plantation trees will serve to broaden the genetic base and simultaneously utilize available genetic variation. Plantation selection must be initiated soon if the scheduling objectives of the third-generation production program are to be met. The proposed schedule is as follows:

a.	Plantation selection	1975 - 1979
b.	Breeding and testing	1980 - 1988
c.	Plantation derived second-generation orchard establishment	1990 - 1998

Genotypes derived from selection and breeding of plantation trees will have been subjected to only two cycles of recurrent selection which will be combined with the third-generation material already available. Thus a "catching-up" effort is required from plantation selections which can be successful only if selection intensity is high and environmental effects on candidate selections are minimal. Some control of the environment is realized by selection in plantations established at uniform spacing with trees of the same age. Site preparation prior to plantation establishment normally reduces vegetative competition which reduces environmental extremes.

Genetic gains from the second-generation plantation selections are expected to nearly equal third-cycle recurrent selection of the main line improvement program.

Equally rapid improvement with second-generation selections from the wild tree selections was not possible, since environmental variation was high in the forests from which the original parents were chosen. Additionally selection intensity is lower with the third cycle of selection in the main-line program because of the prevalence of relatedness. Lower selection intensity results in less genetic gain.

Each member of the Cooperative will obtain 100 selections from plantations for each operating orchard. Therefore, each regional program will have from 500 to 1000 new plantation selections. The goal of 100 trees per program per member is not based on optimizing selection intensity or genetic gain, but is the maximum number of trees possible under operational constraints. With large plantation acreage, more trees could be selected with little sacrifice in selection intensity, but manpower resources prevent this.

The plantation selections will be mated using a partial diallel scheme requiring six crosses per clone. This number has been determined according to projected optimization of genetic gain as reported by Squillace (1973). This scheme will result in 1500 to 3000 specific crosses per region with each cooperating organization responsible for 300 crosses over a six to eight year period. The task is large, but rewards are considerable. This effort will enable each regional program to carry forward (beyond the third generation) a breeding population varying in size from 250 to 500 unrelated, fully pedigreed lines. More importantly, significant genetic gains in the third and subsequent generations will be attainable.

Plans to combine trees from the plantation selection and breeding phase with the main-line breeding phase of the program require comparison testing. This is essential to insure that plantation derived material resulting from only two cycles of selection will perform on a par with trees of the original program subjected to three cycles of recurrent selection. The testing for comparative purposes is operationally feasible since the two phases of program development are coincidental in time.

The opportunity for expansion of the genetic base through this third phase of the program is considerable, yet it will require a substantial commitment of resources to insure success. If such a commitment is not made soon the opportunity will be lost since most plantations of loblolly pine in the recent past and near future will be from seed orchard derived stock. As the vast acreages of unimproved plantations that now exist are harvested, a genetic resource with tremendous potential will disappear forever. Failure to take the needed action will severely restrict the future potential for genetic gain and its use to enhance forest productivity.

THE COOPERATIVES FUTURE STRATEGY - APPLICATION

The N. C. State Cooperative Tree Improvement Program applies genetic improvement methods to increase the quality and productive potential of forest plantations. The end products of these research and development efforts are improved trees. A regional program concept is to be followed in all future development as a means to increase efficiency and better utilize resources. Within each region, established-production seed orchards provide the "pay off" by producing large quantities of genetically improved seed. Each new orchard in the development sequence will pay greater dividends than the previous one in terms of genetic gain for a complex of economically important traits. Successive seed orchards overlap in time; older orchards will be phased out as newer and better ones commence seed production.

The selection, breeding and testing program provides the foundation of genetic resources on which the future production orchard effort depends. As breeding develops

successive generations of better trees, the very best are selected for inclusion in production orchards. Short intervals between successive generations will result in greater gain per unit time; generally applied programs become more profitable as generation intervals decrease (Squillace and Gansel, 1972). Selection, breeding and testing strategy must be responsive to the pressure of time as this relates to maximizing profitability, a goal of every applied program.

In the long term, a breeding program must provide for effective base population resynthesis on a recurring schedule. The breeder should strive for control of coancestry in order to retain flexibility while developing production orchards with maximum selection differential to develop the greatest gain. The program must be flexible to accommodate a dynamic population. Breeding populations will be continually built up with new and better selections and purged of trees which fail to maintain the required measure of superiority. Continued emphasis on selection for general combining ability is appropriate since this is the only source of variation that can be effectively utilized with current tree improvement technology.

The proposed management strategy for genetic resources of the N. C. State Cooperative maintains a realistic balance between the short and long-range objectives. Production orchards have been established and many are now producing near expected capacity. New and better orchards are currently being created; others will become reality as trees with higher genetic value become available from the breeding program. Breeding strategy is planned to develop additional genotypes for maximum immediate utilization and to provide for a broad genetic base suitable for long-term recurrent selection and breeding.

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PROVENANCE STUDY OF FIVE GEOGRAPHIC SOURCES OF LOBLOLLY PINE

Lee Draper, Jr. [1/]

Abstract.--Five geographic seed sources of loblolly pine (Nassau and Marion Counties, Fla.; Telfair and Schley Counties, Ga.; and Conecuh County, Ala.) were planted near four of the areas of seed origin. After five years in the field, the Marion source had greater mean volume production and lowest average per cent rust infection. The Telfair and Nassau sources were second in growth performance with the Schley source ranking second in lowest per cent rust incidence.

Additional keywords: Pinus taeda, survival, volume growth Cornartium fusiforme resistance.

The increasing demand for loblolly pine seedlings in Container Corporation of America's reforestation program made it imperative that a serious look be taken at the loblolly seed sources available within the geographic boundaries of the Company's holdings and their performance within these limits. Such information is needed for making intelligent decisions as to where future seed collections should be made, as well as the most desireable geographic source to be used in the expanding and establishment of loblolly pine seed orchards. The Marion source was of particular interest because of outstanding growth and form of stands in the area. This same source had been a top growth performer in progeny tests of Continental Can Company, planted in east Georgia.

METHODS

In the fall of 1967 cones were collected and kept separate from five individual dominant and codominant loblolly trees in Marion and Nassau Counties, Fla.; Telfair and Schley Counties, Ga.; and Conecuh County, Ala.[2/] (fig. 1). Seed from these collections were sown in five replicated blocks at Container's nursery near Brooker, Fla. in the spring of 1968. Each of the five blocks in the nursery was assigned to one of five planting locations. The seedlings were outplanted in the winter of 1968-69. A nested planting design was used with each nest comprised of seedlings from each of the five individual trees planted in four randomized blocks. Trees within each nest were planted in ten tree row plots using a 6' x 10' spacing. A single border row using extra seedlings from the various sources was planted around the outside boundaries of each test.

Planting sites were selected near each of the areas from which the cone collections were made (fig. 1). Necessary steps were taken at all planting sites to keep damage from fire and man at the very minimum. To date these efforts have been quite successful. The Telfair planting was lost due to excessive flooding of the area shortly after planting.

1/ Research Forester, Container Corporation of America, Callahan, Florida.
2/ Seed from the Conecuh was bulked in error.

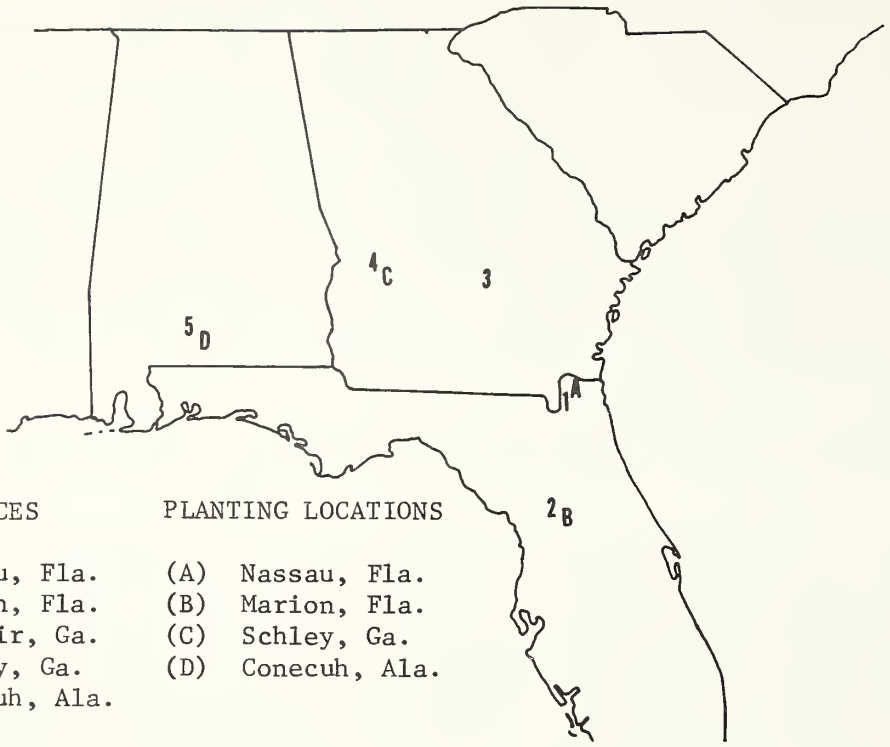

Figure 1.--Sources and planting locations of loblolly pine in Florida, Georgia and Alabama.

Fifth year measurements were made during the winter of 1973-74. Survival, total height, d.b.h., and the incidence of fusiform rust were recorded. Survival is expressed as per cent of total number of trees planted. Volume growth is expressed as average cubic foot volume per tree for the source (Goddard and Strickland 1968).

An analysis of variance was computed by location and over all locations for rust incidence and volume production for all sources. Tuckys mutliple range procedures was used to test for significant differences (at the .05 per cent level of significance) among the ranked seed source means. Variance of of individual families within sources was not analyzed.

RESULTS

Survival

Fifth year survival was very good and averaged near 90% or better at all locations except the Conecuh site where survival ranged from 50-87% (table 1). There was no significant difference between survival of sources at the Nassau, Marion and Schley planting sites. The survival of the Conecuh source was slightly better at each of these sites and out performed all sources when planted in its home county (fig. 2).

Table 1.-- Average survival for five geographic sources of loblolly pine at end of five growing seasons planted at four geographic locations.

Sources	Planting Location				
	Nassau	Marion	Schley	Conecuh	Average
	PERCENT				
Nassau Fla	89.5	89.5	87.5	59.5	81.5
Marion Fla	92.5	88.5	84.5	49.8	78.8
Telfair Ga	93.0	90.5	87.5	66.8	84.4
Schley Ga	94.0	90.5	93.5	59.8	84.4
Conecuh Ala	96.0	93.5	90.0	86.5	91.5
Average	93.0	90.5	88.6	64.5	

Inexperienced planting labor and adverse weather conditions could possibly explain the lower average survival at the Conecuh site; although these factors did not have too much effect on the Conecuh source. The overall good survival of this source can probably be traced to some physological aspects.

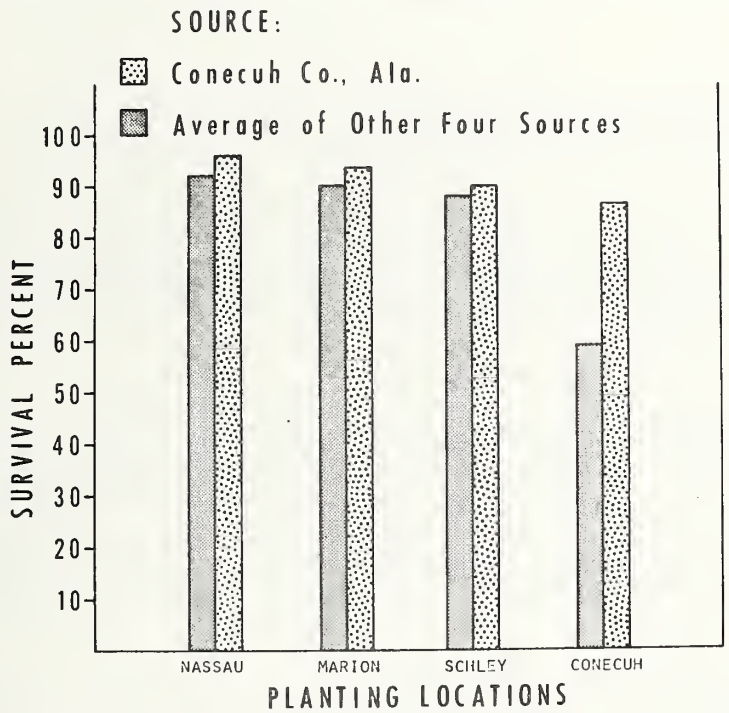

Figure 2.-- Survival of loblolly pine comparing Conecuh Co., Ala. source with average for other four sources at four planting locations.

Growth

Volume growth varied considerable between planting sites due to differences in site quality. Growth at the Marion, Schley and Conecuh sites was depressed to some degree by damage from Nantucket pine tip moth (Rhyacionia frustrana Comst.). Total mean volume production at the Nassau location was almost twice that at the other sites (table 2).

Table 2.-- Mean volume growth per tree for five geographic sources of loblolly pine at end of five growing seasons planted at four geographic locations.

Sources	Planting Location				
	Nassau	Marion	Schley	Conecuh[a/]	Mean Volume[b/]
	CUBIC FOOT				
Marion Fla	.28	.12	.15	.08	.16
Nassau Fla	.21	.08	.13	.07	.12
Telfair Ga	.20	.07	.13	.08	.12
Schley Ga	.19	.05	.10	.08	.11
Conecuh Ala	.18	.05	.11	.09	.10
Mean Volume	.21	.07	.12	.07	

a/ Mean volume at end of sixth growing season.
b/ Means within a single bracket are not significantly different.

The mean growth for all planting sites was significantly better for the Marion source. This source was also more productive at individual planting locations except the conecuh site where there was no significant difference in volume growth between sources

Fusiform rust

There was considerable variation in rust infection between planting locations. Although per cent rust incidence at the Schley planting closely paralled the rates of infection reported for this area in the fusiform rust incidence survey 1971-1973, the per cent infection at Conecuh was much lower than survey figures (Phelps 1974). No comparisons could be made for the Florida plantings since loblolly pine was not sampled for this area in the rust survey.

Container has several acres of loblolly plantings scattered throughout an eight thousand acre tract in Marion County, Florida. The Marion planting site is located within the boundaries of said property. Our past surveys have shown that the per cent of rust infection is much greater for loblolly than slash in this specific area. Latest survey figures show the average rust incidence to be 47.0% for loblolly and 8.0% for slash.

While the average rust infection for the Marion source was lower than all other sources, it was not significantly different from the Schley and Conecuh sources (table 3). The Marion source had the lowest rust incidence at all planting locations except at Schley, where the per cent of infection for the local source was slightly lower. However, even at the Schley site the percent rust infection for the Marion source was less than the average for all sources (fig. 3).

Table 3.-- Average per cent rust infection of five geographic sources of loblolly pine at end of five growing seasons planted at four geographic locations.

Sources	Planting Location				
	Nassau	Marion	Schley	Conecuh	Average[a/]
	PERCENT				
Nassau Fla	29.8	77.5	73.2	14.5	48.8
Telfair Ga	22.5	69.0	70.3	21.5	45.8
Conecuh Ala	22.0	64.5	64.5	20.2	42.8
Schley Ga	26.2	60.0	59.0	19.8	41.3
Marion Fla	18.3	48.8	64.0	12.5	35.9
Average	23.8	64.0	66.2	17.7	

[a/] Means within a single bracket are not significantly different.

CONCLUSION

Based on fifth year performance, Marion Co. loblolly is the best of all local seed sources to use in the reforestation of Container's land holdings in Florida and Georgia.

In the west Georgia area, rust infection of loblolly is a serious problem and, based on our limited data, the same could be true for Marion Co., Florida. In lieu of these facts, a second choice for loblolly seed source would be seed collected in the west Georgia area.

These requirements fit a close pattern with Container's holdings since our largest acreages of loblolly pine fall within the boundaries of these two geographic areas.

However, (Wells 1969) indicated the superior rust resistance and growth of Livingston Parrish and high rust resistance of east Texas loblolly sources when planted in the general geographic areas of Container's holdings. Investigation is continuing on the suitability of these external sources on Container's lands.

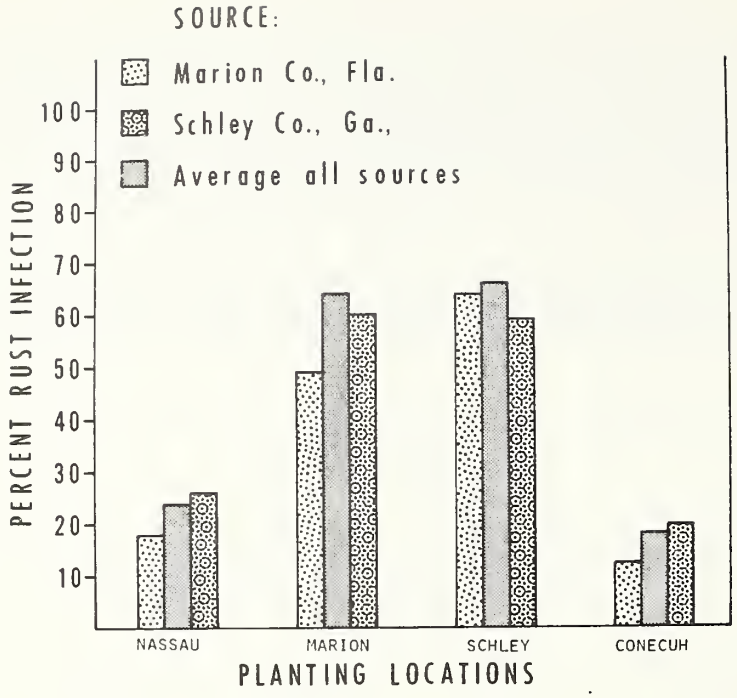

Figure 3.-- Average per cent rust infection of loblolly pine comparing Marion Co. Fla. and Schley Co., Ga. sources with average for all other sources at four planting locations.

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DISTRIBUTION OF NITROGEN, PHOSPHORUS, POTASSIUM, AND CALCIUM IN TEN FAMILIES OF PINUS VIRGINIANA (Mill.)

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Abstract.--Half-sib progeny from ten selected Virginia pine trees were grown on two randomized blocks and harvested at age eight. The concentration (%) and the total content (g) of N, P, K, and Ca was determined for each component of each tree. Significant family effects were observed for Ca concentration in bolewood and for Ca content in bolebark. Block effects were significant in many instances.

Virginia pine (Pinus virginiana Mill.) is a desirable source of pulpwood in several southern states (Thor, 1964). The practice of whole-tree utilization will probably be more widely applied throughout the South in the coming years (Koch, 1973), and can be applied to Virginia pine. Increased nutrient removal from the site due to whole-tree harvesting may create nutrient deficiencies, particularly on marginal sites (Weetman and Webber, 1972; Boyle et al., 1973). Since Virginia pine frequently occurs on poor sites (Snow, 1965), nutrient losses may be an important consideration for management of this species under a whole-tree harvesting system. The objectives of this study were to determine the concentrations of N, P, K, and Ca in the aboveground components of selected Virginia pine trees, to estimate the total content of these nutrients in the trees, and to determine whether or not genetic variation has a significant effect on either the concentration or the total content of nutrients in eight year-old Virginia pine.

METHODS

In September, 1963, seed was collected from twenty Virginia pine trees on the Lee Experimental Forest in Buckingham County, Virginia (Bramlett, 1965). After germination in a nursery bed, seedlings were outplanted into two adjacent randomized blocks on the Lee Forest, with one 3-tree by 5-tree plot for each family in each block. At age eight, Matthews (1974) cut every third tree in each row at ground level. This provided a sample of five trees from each family on each block, less any dead trees. Data on dry matter production and distribution was collected and analyzed by Matthews (1974).

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Due to time limitations, the sample to be analyzed for nutrient content was narrowed from twenty families to ten. Families in which more than two trees were missing were eliminated. From the remaining families, ten were chosen which represented the range of diameter and height measurements.

Each tree was separated into four components: foliage, branches, bole-bark, and bolewood. The N, P, K, and Ca concentration in each component of each tree was determined. This data was combined with the dry matter distribution data developed by Matthews (1974) to estimate the total content of each nutrient in each component of each tree. Analyses of variance were performed to determine if significant among family differences were present in the concentration or in the total content of each nutrient in each tree component.

RESULTS AND DISCUSSION

Fourteen significant differences in nutrient concentration or total content were found (Table 1). Only two of these were due to the effect of family: Ca concentration in bolewood and Ca content in bolebark. The remaining twelve differences were due to the effect of block. Thus, it can be said that genetic variation had little effect on either concentration or total content of these nutrients. Environmental variation is clearly of major importance. There is currently no detailed site information available which might offer an explanation of the environmental effect.

The results of this study indicate that attempts to influence nutrient uptake (and therefore nutrient loss due to harvesting) through selective breeding of Virginia pine would be futile. However, it must be remembered that the parents of all trees used in this study were located on the Lee Experimental Forest (Bramlett, 1965), and therefore represent only a small portion of the range-wide genetic variation existing in Virginia pine. Perhaps an experiment using seed collected over a larger area would reveal some effects of genetic variation on nutrient uptake.

It should be noted that previous studies concerning the effect of genetic variation on nutrient concentration show somewhat variable results. Giertych and Farrar (1962) tested nine provenances of jack pine and found no significant differences in foliar N concentration due to provenance; however, Mergen and Worrall (1965) tested several provenances of this species and did find significant differences in N, P, and K concentrations. Gerhold (1959) found significant differences in foliar concentrations of N and Ca between six races of 19 year-old Scots pine, but differences in P and K were not significant. Steinbeck (1966), working with the foliage of five year-old Scots pine, found significant differences between provenances for concentrations of N and P, but not for K and Ca.

Presumably most of these differences in results are due to the fact that the researchers used different sets of provenances. Within a given species, genetic variation may influence nutrient uptake, but this effect may or may not be detectable within a selected group of provenances or families. In the future, researchers who hope to detect any significant effect of genetic variation on nutrient uptake would be wise to use a sample as large and as diverse as possible.

Table 1: Significant differences observed in analyses of variance for concentrations (%) and total content (g) of N, P, K, and Ca among ten families of Virginia pine.

Stand Component	Variable	Source of Variance	F Value
Foliage	P concentration	Block	6.62*
	K concentration	Block	44.22***
	K content	Block	8.84*
Branches	P concentration	Block	8.00*
Bolewood	K concentration	Block	68.00***
	Ca concentration	Family	5.25*
	Ca concentration	Block	24.00***
	P content	Block	18.30**
	K content	Block	14.98**
	Ca content	Block	7.33*
Bolebark	P concentration	Block	14.00**
	K concentration	Block	13.00**
	K content	Block	22.92***
	Ca content	Family	4.20*

* significant at P = .05
** significant at P = .01
*** significant at P = .001

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ESTIMATES OF SELFED SEEDLING PRODUCTION FROM A SLASH PINE SEED ORCHARD BASED ON GENE MARKERS

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Abstract.--Ramets of slash pine clones carrying genes for chlorophyll deficiencies in the early post-germination stage were used to estimate natural selfing in grafted seed orchards. Percentages of selfed seedlings in wind-pollinated seed orchard collections averaged 2.6 and ranged from 0.0 to 8.9. Seed collected from ortets in natural stands produced an average of 5.9 percent selfed seedlings.

Additional keywords: *Pinus elliottii*, chlorophyll mutant, albino.

For many years geneticists have wondered how much seed resulting from self-pollination is produced in clonal pine seed orchards? The answer of course will vary from orchard to orchard. One method of estimating the amount of selfing taking place is by the use of chlorophyll-mutant gene markers, particularly those whose effects can be seen shortly after the seed germinate. In this paper data collected between 1967 and 1974 on the frequency of chlorophyll mutants in selfed and wind-pollinated progenies of slash pine seed orchard trees and wind-pollinated progeny of some ortets are used to estimate and compare selfed seedling production in seed orchards and natural stands.

Selfing is known to reduce the yield of sound, viable seed, but data on seed yields are not discussed in this paper.

METHODS

The trees from which data on the occurrence of chlorophyll mutants were collected were in the seed orchards of the Georgia Forestry Commission, or in natural stands or plantations in Georgia. Seed resulting from controlled self-pollination, or from collections of wind-pollinated cones, were sown in flats in a greenhouse, and normal and chlorophyll-mutant seedlings were counted. The wind-pollinated cones were collected from as few as one to as many as 77 ramets per clone. Single-ramet collections included cones from all crown positions, and multiple-ramet collections were usually one cone per tree picked up at random after the tree had been mechanically shaken. The percent of seedlings produced from natural self-pollination in the wind-pollinated progenies was estimated by the relationship:

$$\frac{\text{Number of self-fertilized seedlings in the wind-pollinated seedlot}}{\text{Total number of seedlings in the wind-pollinated seedlot}} \times 100$$

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where the number of self-fertilized seedlings was estimated by:

$$\frac{\text{Total number of seedlings in the selfed seedlot}}{\text{Number of mutant seedlings in the selfed seedlot}} \times \text{Number of mutant seedlings in the wind-pollinated seedlot}$$

(Franklin, 1971). For example, M-4 in table 1 is calculated as:

$\frac{29}{4} \times 1 = 7.25$ = estimated number of selfed seedlings in wind-pollinated seedlot.

$\frac{7.25}{616} \times 100 = 1.18$ = percent selfed seedlings in the wind-pollinated seedlot.

The phenotypes of the gene markers for which data were collected are:

B-9, Albino, lethal

C-4, Albino, lethal

D-11, Abnormal primary bud

J-1, Green hypocotyl, nonlethal

M-3, Pale green-yellow cotyledon, lethal before primary growth

M-4, Yellow primary needles, nonlethal

R-7, Pale green primary needles

T-37, light green cotyledon, lethal

W-13, light green cotyledon, lethal

Chi-square tests of segregation ratios of the selfed progenies indicate that all of the above, except D-11, are probable single-gene recessives. D-11 may be heterozygous for two genes, and the mutant phenotype occurs when either or both gene are homozygous recessive in the seedling.

RESULTS

Wind-pollinated seed from seed orchard ramets produced an average of less than 3 percent selfed seedlings (table 1). Seed from ortets in natural stands produced almost 6 percent selfed seedlings (table 1). A very similar estimate of selfing in natural stands of slash pine was reported by Squillace and Kraus (1963).

Table 1.--Summary of counts of seedling phenotypes used for estimation of the frequency of selfed seedlings in slash pine seed orchards and natural stands

Number	Controlled self-pollination		Wind-pollination		
	Seedlings produced		Seedlings produced		Selfed seedlings
	Normal	Abnormal	Normal	Abnormal	
	Number		Number		Percent
B-9	56	3	523	0	.0
C-4	48	11	2907	12	2.2
J-1(1972)	31	8	4257	18	2.0
J-1(1974)	113	15	574	6	8.9
M-3	13	1	2149	1	.6
M-4	25	4	615	1	1.2
T-37	380	91	6406	44	3.5
W-13	41	18	340	0	.0
Average					2.6
	Ortets				
D-11	24	22	296	5	3.5
M-4	25	4	1445	17	8.4
T-37(1967)	380	91	3984	4	.5
T-37(1971)			1254	28	11.3
Average					5.9

DISCUSSION

The low estimates of selfing in these grafted seed orchards are encouraging because it had been expected that pollination between ramets of the same clone might produce relatively high percentages of selfed seedlings. All of the clones used in this study were planted in five-ramet rows, so the chances of selfing were higher than in most seed orchards where clones are mixed to minimize selfing between ramets.

Three possible explanations for the differences between seed orchard selfing and that found in natural stands are:

1. Inbreeding in natural stands from crossing of relatives may be inflating estimates of selfing.

2. Embryonic competition favors outcrossed embryos over embryos resulting from selfing (Franklin, 1974). Embryonic competition may be especially keen in seed orchards where most, if not all, of the clones are unrelated. More of the selfed embryos may be competing with unrelated embryos in seed orchards than in natural stands.

3. Under seed orchard conditions more fertilizations per ovule may take place, further increasing the competition among embryos and eliminating the less vigorous selfed embryos.

CONCLUSIONS

Gains from tree breeding efforts will probably not be substantially affected by growth losses caused by selfing in most slash pine seed orchards. Even though there are chances of selfing among ramets as well as within ramets, the production of selfed seedlings in seed orchards is apparently no greater than it is in natural stands. Trees carrying genes for chlorophyll deficiencies are good material for monitoring self-pollination and may be worth retaining in seed orchards if their breeding values for production traits are not too low.

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TEN-YEAR RESULTS OF AN OPEN-POLLINATED PROGENY TEST OF LONGLEAF PINE IN SOUTH CAROLINA[1/]

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ABSTRACT. In March 1966, 1-0 seedlings from 50 open-pollinated mother trees of longleaf pine were planted in Aiken County, South Carolina. The site was a sandy barren with typical sandhill vegetation of scrub oak and longleaf pine which was mechanically removed prior to planting. The design was a 10-tree row plot, randomized complete block with 5 replications. In November 1974 all trees were tallied for survival and measured for height. Significant differences were found among the progenies for both traits. Heights averaged 6.6 meters (21.6 ft.) for the best progeny and 4.4 meters (14.3 ft.) for the poorest. Survival ranged from 4 to 76 percent among the different progenies. There was no correlation between survival and height. The results indicate that selection for either good growth or high survival would achieve satisfactory results but that combining the two characteristics would best be accomplished by screening a large number of progenies.

Additional keywords: Height growth, survival, grass-stage, brownspot, Pinus palustris, Scirrhia acicola.

In southeastern United States, longleaf pine (Pinus palustris Mill.) has not received as much attention from forest tree breeders as the more widely-planted loblolly (P. taeda L.) and slash (P. elliottii Engelm.) pines. This means that there is little information on the amount of variation in survival, disease resistance, and height growth of progeny lines (families) derived from individual mother trees. This study reports on the 10-year performance of 50 unselected longleaf pine progenies of South Carolina provenance, planted on a typical longleaf site in Aiken County, South Carolina. The results should be of interest to tree breeders, silviculturists, and forest managers contemplating the use of this species in plantations on similar sites.

METHODS

In October 1964 seed was collected from 192 longleaf pine trees in 33 counties of South Carolina. This seed was sown in beds of the South Carolina State Forestry Commission's Ridge nursery in November. The seedlings were

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lifted as 1-0 stock in March 1966. Because of spotty germination and low survival in many seed lots, only 50 lots yielded enough seedlings to plant a 5 replicate, 10-tree row plot in a randomized complete block design. The site was a sandy barren from which the native vegetation, consisting mainly of scrub oak (Quercus spp.) and longleaf pine was mechanically removed prior to planting. The plantations were examined 7 times in the ensuing 9 years. The latest examination was made in December 1974 when the trees were 10 years old. Examination parameters included survival, number of trees in a "grass stage" (not showing height growth), number of trees severely attacked by the brownspot disease organism (Scirrhia acicola (Dearn.) Siggers), and height (Table 1). Analyses of variance, using the RCB(random model)(Steele and Torrie, 1960), were performed to determine whether differences in the measured traits could be accounted for by individual progenies.

Table 1. History of examinations of a longleaf pine progeny test in Aiken County, South Carolina

Information	Date: Mo./Yr.	Age of Trees[a/]	Examination Parameters
Seed Collected	10/64	0	-
Seed Sown	11/64	0	-
Seedlings lifted	3/66	1	-
Seedlings planted	3/66	1	-
1st examination	1/67	2	Survival
2nd examination	12/67	3	Survival, Grass Stage, Brownspot, Height
3rd examination	3/69	4	Survival, Grass Stage, Brownspot, Height
4th examination	4/70	5	Survival, Grass Stage, Brownspot, Height
5th examination	5/71	6	Survival, Grass Stage, Brownspot, Height
6th examination	5/72	7	Survival, Grass Stage, Brownspot, Height
7th examination	12/74	10	Survival, Height

a/ Counted in terms of growing seasons completed since seeds were sown.

RESULTS

Survival

Longleaf pine characteristically has low initial survival when compared with other southern pines (Wakeley, 1954). This proved true in the present study in which the average survival at age 2 was only 53.6 percent (Table 2). After 10 years there was a further decline to 41.7 percent. There were, however, significant differences among progenies for this trait (Table 6), suggesting that genetic factors may be at least partially responsible. Environmental factors that may have affected the results, and were not controlled, included seedbed location and seedbed density in the nursery. The trees were planted over a two-day period by an experienced planting crew.

Table 2. Survival by frequency classes of 50 longleaf pine progenies at selected ages in an Aiken County, South Carolina plantation

Survival Frequency Class (Percent)	No. of Progenies at Stated Ages 2	4	6	10
91-100	0	0	0	0
81-90	4	1	0	0
71-80	6	4	3	1
61-70	9	6	5	5
51-60	8	9	11	8
41-50	9	11	9	11
31-40	7	9	12	12
21-30	4	7	6	9
11-20	2	1	2	2
0-10	1	2	2	2
Mean Survival Percent	53.6	47.2	44.7	41.7

Grass Stage

Longleaf pine does not begin height growth at once, but remains in a stemless condition known as the "grass stage" for 2 to 5 years or more, during which the taproot enlarges and elongates, and the terminal bud thickens (USFS, 1965). The progression out of the "grass" for the 50 progenies is shown in Table 3. Most differences among the progenies occurred at ages 3 and 4, when they were spread over 7 frequency classes. At the end of the sixth year, virtually all seedlings had started height growth. Ability to begin early height growth is undoubtedly influenced by several genetic and environmental factors. Among these are root size and length, terminal bud diameter, and physiological condition of the seedling, some of which may be inherent and some of which may be affected by seedbed density, soil fertility, etc. External factors affecting grass stage persistence could include disease (especially brownspot needle blight), and competition from sprouts and non-woody plants at the planting site.

Severe Brownspot Infection

Brownspot needle disease (Scirrhia acicola) is the major pathogen of longleaf pine seedlings and can either kill young trees outright or prolong the grass stage indefinitely. Data were first taken on brownspot infection in the third year. Although initially all trees had some disease-infected needles, severe infection (needle surface 50 percent brown as estimated by eye) was much less. The data showed that brownspot infection increased through age 5, then rapidly declined (Table 4). At age 5, the progenies affected by severe brownspot were spread over 8 frequency classes. Actual mortality caused by this disease was not tallied, but it undoubtedly played a role in the declining survival from the third through the sixth year. Significant differences (Table 6)

in severity of infection among the 50 progenies suggests strongly that genetic factors were responsible for some of these results.

Table 3. Frequency of trees in the grass stage of 50 progenies of longleaf pine at selected ages in an Aiken County, South Carolina plantation

Grass Stage - Frequency Class (Percent)	No. of Progenies at Stated Ages				
	2	3	4	5	6
91-100	50	4	0	0	0
81-90	0	7	0	0	0
71-80	0	11	1	0	0
61-70	0	15	0	0	0
51-60	0	7	2	1	0
41-50	0	5	4	2	0
31-40	0	1	10	2	0
21-30	0	0	12	9	0
11-20	0	0	13	15	0
0-10	0	0	8	21	50
Mean Percent of Trees in Grass Stage	100	65.7	24.4	14.4	0.1

Table 4. Frequency of trees with severe brownspot infection of 50 longleaf pine progenies at selected ages in an Aiken County, South Carolina plantation

Severe Brownspot - Frequency Class (Percent)	No. of Progenies at Stated Ages				
	3	4	5	6	7
91-100	0	1	0	0	0
81-90	0	0	0	0	0
71-80	0	0	1	0	0
61-70	0	1	1	0	0
51-60	0	2	2	1	0
41-50	0	5	8	0	0
31-40	0	7	12	1	0
21-30	3	12	14	1	1
11-20	20	15	8	10	1
0-10	27	7	4	37	48
Mean severe brownspot infection	9.4	24.9	31.5	6.6	3.2

Height

Height growth of longleaf pine is strongly influenced by time in the "grass." In the measurements shown, only seedlings actively showing height growth at the time of the various measurements were included. Seedlings showing height growth averaged 2.0 feet at age 4, 8.5 feet at age 7, and 18.7 feet at age 10 (Table 5). The spread among progenies at age 10 ranged over 6 frequency classes, and significant differences (Table 6) were shown. Although influenced both by length of time in the grass stage and severity of brownspot infection, it is reasonable to conclude that some of the differences in height shown among the progenies are inherent.

Table 5. Frequency of heights in feet of 50 longleaf pine progenies at selected ages in an Aiken County, South Carolina plantation

Mean Height Frequency Class (Feet)	No. of Progenies at Stated Ages 4	7	10
0- 2.0	23	0	0
2.1- 4.0	27	1	0
4.1- 6.0	0	8	0
6.1- 8.0	0	21	0
8.1-10.0	0	14	0
10.1-12.0	0	5	0
12.1-14.0	0	1	2
14.1-16.0	0	0	6
16.1-18.0	0	0	15
18.1-20.0	0	0	15
20.1-22.0	0	0	9
22.1-24.0	0	0	3
Mean Height (Feet)	2.0	8.5	18.7

Correlations

Correlation coefficient matrices were obtained for the 6 sets of data involving the 4 measured traits (Table 7). Survival was not significantly correlated with height at any age. Third year brownspot infection was negatively correlated with survival only at ages 7 and 10. Survival/grass stage correlations were mostly weak and non-significant. The height/grass stage correlations were negative with these two traits showing complementarity. Progenies remaining in the grass stage were poor growers, and good growers were those that overcame the grass stage at an early age. Correlations between brownspot infection and grass stage were positive. Thus, a high incidence of brownspot infection was correlated with a high proportion of trees in the grass stage and this effect generally held for several years. Brownspot infection class was negatively correlated with height growth, i.e., progenies having high brownspot infection rates were also slower growing. This effect lasted as long as 4 years for those progenies that were attacked by the disease organism at an early age.

Table 6. Analyses of variance for percent survival, grass stage, severe brownspot infection, and total heights at selected ages of 50 longleaf pine progenies in an Aiken County, South Carolina plantation[a/]
(RCB - Random Model)

		----Mean Squares ----		
Percent Survival				
Source	df	Age 2	Age 6	Age 10
Block	4	164 ns	185 ns	111 ns
Progeny	49	1936 **	1445 **	1251 **
Error	196	287	271	276
Grass Stage				
Source	df	Age 3	Age 4	Age 5
Block	4	2968 **	690 ns	558 ns
Progeny	49	1156 **	991 ns	568 ns
Error	186	729	720	509
Severe Brownspot				
Source	df	Age 3	Age 5	Age 7
Block	4	178 ns	729 ns	61 ns
Progeny	49	245 ns	920 *	275 **
Error	186	248	579	106
Mean Plot Heights				
Source	df	Age 4	Age 7	Age 10
Block	4	.047 ns	33.5 ns	52.1 ns
Progeny	49	.042 **	36.6 **	60.4 **
Error	188	.022	17.4	34.9

a/ ** = Significant at 1% level
* = Significant at 5% level
ns = Non-significant

Table 7. Correlation coefficient matrices at selected ages for six sets of data among four traits of 50 longleaf pine progenies in an Aiken County, South Carolina plantation [a/]

Height (Age)

Survival (Age)	3	4	5	6	7	10
2	.22	.23	.10	.08	.04	.21
3	.21	.21	.09	.07	.03	.18
4	.23	.18	.06	.04	.01	.10
5	.25	.24	.10	.08	.04	.11
6	.23	.23	.09	.06	.02	.11
7	.24	.25	.12	.10	.06	.11
10	.23	.26	.14	.15	.13	.12

All correlations are non-significant

Brownspot Infection (Age)

Survival (Age)	3	4	5	6	7
2	-.10	.06	.18	.05	.21
3	-.11	.06	.16	.03	.19
4	-.18	.03	.15	-.02	.16
5	-.22	-.01	.14	-.03	.14
6	-.22	-.01	.17	-.02	.11
7	-.28*	-.05	.13	-.10	.07
10	-.31*	-.09	.09	-.15	.03

33 of 35 correlations are non-significant

Height (Age)

Grass Stage (Age)	3	4	5	6	7	10
3	-.99*	-.65*	-.58*	-.51*	-.44*	-.28*
4	-.55*	-.84*	-.70*	-.69*	-.63*	-.40*
5	-.35*	-.40*	-.62*	-.51*	-.51*	-.29*
6	-.27	-.36*	-.45*	-.48*	-.50*	-.16
7	.17	.07	-.13	-.18	-.31*	.10

Significant negative correlations are shown for 23 of 30 comparisons

Brownspot Infection (Age)

Grass Stage (Age)	3	4	5	6	7
3	.25	.11	.22	.24	-.15
4	.39*	.34*	.10	.29*	.02
5	.29*	.14	.34*	.58*	.15
6	.38*	.33*	.42*	.56*	.11
7	.31*	.39*	.18	.38*	.83*

Significant correlations are shown for 14 of 25 comparisons

Grass Stage (Age)

Survival (Age)	3	4	5	6	7
2	-.21	-.22	.15	.15	.11
3	-.21	-.21	.12	.12	.09
4	-.23	-.20	.13	.11	.08
5	-.25	-.26	.11	.12	.05
6	-.23	-.26	.12	.13	.04
7	-.24	-.28*	.07	.06	-.01
10	-.23	-.27	.06	.04	-.10

34 of 35 correlations are non-significant

Brownspot Infection (Age)

Height (Age)	3	4	5	6	7
3	-.25	-.11	-.22	-.25	.15
4	-.41*	-.46*	-.22	-.26	-.04
5	-.40*	-.40*	-.35*	-.37*	-.08
6	-.41*	-.41*	-.41*	-.45*	-.13
7	-.40*	-.40*	-.42*	-.48*	-.23
10	-.16	.12	-.10	-.20	.18

Significant negative correlations are shown for 14 of 30 comparisons

[a/] * Significant at the 5% level

DISCUSSIONS AND CONCLUSIONS

In longleaf pine, progeny differences up to age 10 are clearly shown for survival, height growth, time in the grass stage, and severity of brownspot infection. The data suggest that inherent differences among progenies exist for these traits although, because of several uncontrolled environmental factors, the degree of genetic control could not be estimated.

The correlation values can be useful in assessing early results of a breeding program in longleaf pine. The lack of correlation between height growth and survival indicates that the traits may be independent. Thus, to obtain good growth and high survival, twice as many parents should be tested as would be necessary if the two traits were highly correlated. Conversely, selecting parents whose progenies showed early height growth indicates not only that their length of time in the grass stage would be reduced but also that severity of brownspot infection would be lessened.

Longleaf pine breeding might well begin by the selection of large numbers of parents of above average quality, growing open-pollinated progenies, and roguing those parents whose progenies show (1) low first-year survival, (2) have high brownspot infection rates, and (3) remain in the grass stage beyond the third year. The remaining progenies would be carried for 10 years or longer to show outstanding growers. Given complete independence with 50 percent roguing, 500 parents could be evaluated and reduced to 62 at the end of the fourth year, and to 31 at the end of the tenth year. However, it is very likely that complete independence will not occur; and the degree of roguing required may be less than 50 percent. A clonal seed orchard could be delayed until after the fourth year when most inferior parental types would be identified and discarded. It would be further rogued at the tenth year when poor growers among the progenies would be identified.

In longleaf pine, several planned breeding programs are currently underway. On the basis of this limited study, there is evidence that such programs can be successful in developing a superior strain of this valuable species.

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POND X LOBLOLLY HYBRID TEST

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Abstract.--In 1967 controlled pollinations were made with pollen from two loblolly clones on four pond pine clones in the Westvaco Dare County seed orchard. One pond pine failed to set any cones; the other three clones averaged 67 percent cones from strobili pollinated. Seeds per cone averaged 56. Seventy-three percent of seeds sown in the nursery developed plantable 1-0 seedlings. Hybrid height exceeded progeny of the parents in the nursery and has continued in some lines to be equal or better than loblolly through field age 5. Winter coloration in the nursery resembled pond pine. Five replicated tests were planted in 1970 in the South Carolina Coastal Plain and Sandhills, and in west Tennessee and Kentucky. Survival is as good as in the parent lines. Fusiform rust incidence and tip moth damage are intermediate between the parent lines.

Additional keywords: Pinus serotina, Pinus taeda, controlled pollination, tip moth, fusiform rust

INTRODUCTION

Pond pine (Pinus serotina Michx.) and loblolly pine (Pinus taeda L.) are both viewed taxonomically as members of the Australes subsection of the genus Pinus (Critchfield & Little 1966). The two species are sympatric through most of the pond pine range, but they apparently maintain their identity by differing flower phenology, the last loblolly pollen usually having flown two to three weeks before the first pond pine strobili are receptive. However, under these circumstances it is not surprising that they will hybridize, and, in fact, both natural and artificial hybrids have been described.

Schmitt (1968) reported two surviving pond x loblolly hybrids in the Harrison Experimental Forest from crosses made by the Southern Forest Experiment Station in the late 1950's.

At this same time Westvaco control-pollinated pond pine with loblolly pollen to produce the hybrid. Several plantings were established at their Experimental Forest in South Carolina and in Dare County, North Carolina. By age 9 hybrid height in South Carolina averaged 32 feet tall, only 3 feet below loblolly included in the test. These plantings further served as a basis for the development of a hybrid index by Ke Won Kang at North Carolina State University. Against this index he identified several natural pond x loblolly hybrids and progeny from hybrid backcrosses to loblolly in eastern North Carolina (Kang 1966).

Natural hybrids and intergrades were recognized in Maryland and Delaware (Little, Little & Doolittle 1967).

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From these initial observations and pollinations it was apparent, first, that the pond x loblolly hybrid could be expected to occur if loblolly pollen were available for pond pine strobili; and second, that most features of the hybrid would be intermediate between the two parent species.

The study reported here was conducted to learn whether the pond x loblolly hybrid produced from parent trees that were selected for their desirable traits would develop into high quality trees themselves that might provide an improved tree for pond pine sites.

HYBRIDIZATION

Westvaco established a seed orchard in Dare County, North Carolina, one part composed of loblolly pine selections from deep organic soils, the other part composed of pond pine selections, all from Dare and Tyrrell Counties. In 1967 controlled pollinations were made with fresh pollen from two loblolly clones applied to each of four pond pine clones. Loblolly clones 11-544 and 11-551 were selected as the pollen source because they were the last two to shed pollen in that orchard and thus were the most likely to generate hybrids during a late spring. Three of the pond pine clones, 11-533, 11-546, and 11-550 were selected for hybrid pollinations because from 1/3 to 1/2 of previous controlled pollinations for the pond pine progeny testing had developed to cones, a cone yield above average performance there. These three clones were among the earliest in flower emergence in the orchard, usually becoming receptive about two weeks after the last loblolly pollen had flown. One other pond pine clone, 11-538, was selected for hybridization on the basis of the excellent form of its ramets, even though controlled pollination success on it had been below average.

Through the remainder of this report the 11- prefix which serves as a company identification in the N. C. State Coop. will be omitted.

Among the eight possible hybrid crosses from 17 to 29 strobili were pollinated in each cross. All 17 of the 538 x 544 cross and all 22 of the 538 x 551 cross failed to develop as far as yearling conelets, thus, the hybrid test proceeded with six hybrid crosses. Pollination success expressed as the percent of control-pollinated strobili that developed into cones that were collected ranged from 47 percent to 95 percent, averaging 67 percent (Table 1). Seeds were extracted by the N. C. State Coop. and a count of total seeds per cross provided. No record was made of the percent of the seeds that were sound. Total seeds extracted per cone averaged 56, ranging by cross from 42 to 75 (Table 1.). No strong clonal effects were evident beyond the failure of 538 to set any cones.

SEEDLING PRODUCTION

Seeds of each of the six crosses were sown in the Claridge Nursery, Goldsboro, North Carolina in 1969. Germination percent was not determined, however, the total number of hybrid seedlings that were planted in test plantings is recorded. Overall, 73 percent of the seeds sown yielded a total of 1283 plantable hybrid seedlings. Again there were no strong clonal effects (Table 1.).

Table 1. -- Pond x loblolly hybrid seed and seedling yields.

Cone yield: cones collected/strobili pollinated

	Pond 533	Pond 546	Pond 550	Loblolly averages
Loblolly 544	17/18, 95%	13/28, 47%	18/24, 75%	48/70, 69%
Loblolly 551	10/17, 59%	16/29, 55%	19/23, 83%	45/69, 65%
Pond Averages	27/35, 77%	29/57, 51%	37/47, 79%	93/139, 67%

Seeds per cone: seeds extracted/number of cones

	Pond 533	Pond 546	Pond 550	Loblolly averages
Loblolly 544	63	75	57	65
Loblolly 551	46	42	56	48
Pond averages	55	59	57	57

Seedling yield: seedlings planted/seeds sown at nursery

	Pond 533	Pond 546	Pond 550	Loblolly averages
Loblolly 544	83%	78%	59%	73%
Loblolly 551	77%	67%	75%	73%
Pond averages	80%	73%	67%	73%

In addition to the six hybrid lines open pollinated progeny from the three pond and two loblolly parent clones, and from one mixture of two other loblolly clones that flowered late enough to have probably been predominantly pollinated by the two loblolly parent clones of the hybrid, were raised. In July, at seedling age 7 to 8 weeks, the hybrids were obviously twice as tall, 4 to 6 inches at that time, as seedlings in any of the parent lots. Height superiority of the hybrids persisted through the first year in the nursery producing 1-0 seedlings 12 to 18 inches tall for planting in spring 1970.

Winter coloration of the hybrids remained green in the nursery like the yellow-green color of pond pine and in contrast to the purple acquired by the loblolly lots. This qualitative color characteristic might be helpful in nursery bed selection of hybrids if they could be produced by mass pollination of the reciprocal cross using stored pond pine pollen.

TEST ESTABLISHMENT

The complete test includes six hybrid lots, three loblolly lots, and three pond pine lots. Using the 10-tree row-plot design, one 6 replication main test was planted on an organic bay soil in the South Carolina Coastal Plain. A 3-replication supplemental test was planted on deep sand in the South Carolina Sandhills, substituting a commercial South Carolina Piedmont loblolly plot for the progeny of loblolly 544. Another 3-replication supplemental test was planted on an upland stony silt loam pasture in west Kentucky, substituting a commercial north Mississippi loblolly plot for the progeny of loblolly 544. Surplus seedlings were arranged in two test designs using 25-tree square plots. One 4-replication test on an upland silt loam pasture in west Kentucky includes four hybrid lines, some of the parent pond and loblolly lots, and commercial north Mississippi loblolly. The other test on a sandy loam old cotton field in west Tennessee contains 6 replications balanced to consist each of pond x 544, pond x 551, and north Mississippi commercial loblolly.

Survival of the pond x loblolly hybrids is as good as survival of the parent lots. Survival in the main test in the South Carolina Coastal Plain, in the supplemental test in Kentucky, and in the surplus planting in Tennessee averaged 98 to 99 percent. Survival of the hybrids in the surplus planting in Kentucky averaged 85 percent, somewhat better than the 78 and 71 percents of the pond and loblolly parent lots, but not quite equal to the 89 percent of the commercial loblolly. Strong competition from fescue grass sod is thought to be the cause of the lower survival of this test. The severest test of survival occurred in the Sandhills supplemental test in which 66 percent of the hybrids and also of the pond pine survived. Only 57 percent of the loblolly seedlings from the 551 parent survived, yet 80 percent of the commercial Piedmont loblolly survived. Apparently the hybrid deriving from wet site coastal trees does not show any more drought resistance than the natural progeny of these same trees. Nevertheless, in none of the five test plantings is there any indication of a disadvantage in survival of the hybrids in comparison to the parent lines.

GROWTH & FORM

Total tree height was measured in all five plantings at field age 5 last winter. DBH was measured in the three taller plantings. Best growth was attained in the Tennessee surplus planting where the hybrids averaged 16.1 feet, followed by the South Carolina Coastal planting at 13.2 feet, Kentucky supplemental test 10.7 feet, Kentucky surplus planting 8.9 feet, and last the South Carolina Sandhills supplemental test at 7.7 feet. Pond pine was shortest in the four plantings in which it was included. The parent lines of loblolly pine were tallest in the South Carolina Coastal test where the site most nearly resembled that of the original source, and, consequently, all hybrids were intermediate there. In the Kentucky supplemental test progeny of loblolly 551 averaged 11.1 feet, and all three of the hybrid crosses pond x 551 were slightly shorter averaging together 10.7 feet. In the Sandhills supplemental test the progeny of loblolly 551 averages 7.3 feet, and all three of the hybrid crosses pond x 551 were slightly taller averaging 7.8 feet. No similar comparison can be made with the hybrid crosses pond x 544 because of the initial shortage of progeny from 544. However, the average of all hybrids pond x 544

in the main and two supplemental tests is essentially the same as the average of all hybrids pond x 551 suggesting no differing parent tree influence from the two loblolly parents (Table 2.).

The pattern of average height among the hybrids matches the pattern in the pure pond pine lines where the balanced design of the main and supplemental tests facilitates this comparison (Table 2.). Progeny of pond pines 533 and 550 average 8.3 feet tall; progeny of pond pine 546 are 6 percent taller. Hybrids of pond pines 533 and 550 average 10.2 and 10.3 respectively; hybrids of pond pine 546 are 8 percent taller at 11.1 feet.

Four of the test sites were recognized initially as so foreign from the native source that a local or more suitable source of loblolly pine was included in the design as a control. In the Sandhills although the average height of the hybrids is taller than North Carolina Coastal loblolly, the local South Carolina Piedmont loblolly exceeded the hybrid average by 15 percent. Only one hybrid cross, 546 x 544, equalled the local material.

In the Kentucky and Tennessee plantings the commercial loblolly was reportedly of north Mississippi seed source raised in the Tennessee nursery. This commercial source was inferior in height and form to nearly all plantings of the hybrid crosses and was not consistently better than the North Carolina Coastal loblolly. In the Tennessee planting total volume on a per acre basis equalled 227 cubic feet for the commercial loblolly, 228 cubic feet for hybrids pond x 551, and 182 cubic feet for the hybrids pond x 544. The differences are statistically non-significant. The smaller volume of the hybrids pond x 544 results from four of the six replications containing the consistently smallest hybrid, 533 x 544. The similar volume between the commercial loblolly and hybrids pond x 551 results from a smaller diameter in the hybrids compensating their 0.8-foot taller average height.

Form in the hybrids is noticeably better than in the commercial loblolly and thus seems to reflect some of the qualities for which the parent trees were selected. Stem straightness and crown form were subjectively assessed on a scale of decreasing quality from 1 to 6. Hybrids graded 3.61 for straightness compared to 4.87 for commercial loblolly in the Kentucky supplemental test. Crown form of the hybrids there graded 3.64 compared to 4.43 for commercial loblolly.

Part of the cause of poorer height growth and form in loblolly than in the hybrids in the two Kentucky plantings is preferential infestation of pure loblolly by Nantucket pine tip moth. In the Kentucky supplemental test trees were scored as damaged by tip moth if the main stem was crooked due to larval feeding. From age 3 to age 5 the intensity of damage has decreased but the pattern remains that of lowest damage to pond pine, now 12 percent of the trees showing crook, intermediate damage to hybrids with 24 percent of the trees crooked, and highest damage to loblolly pine with 86 percent of the trees deformed.

Uniformity expressed as the coefficient of variation was calculated for tree heights. Within the 25-tree plots of the Tennessee test the coefficient of variation ranges from 10 to 18 percent in the six plots of commercial

Table 2. Pond x Loblolly Hybrid Height in Feet at Plantation Age 5.

Test Planting	Pond 533	Pond 546	Pond 550	Pond Avg.	Lob. 544	Lob. 551	Lobs. 516 & 530	Comm. Lob.	Hybrid 533 x 544	Hybrid 533 x 551	Hybrid 546 x 544	Hybrid 546 x 551	Hybrid 550 x 544	Hybrid 550 x 551	Hybrid x 544	Averages x 551
S. C. Coastal Main Test	10.87	10.39	10.04	10.43	15.35	14.40	13.13		12.56	13.43	13.35	13.46	13.46	12.77	13.12	13.22
S.C. Sandhills Supplemental	6.02	7.26	5.90	6.39		7.28	6.39	8.89	7.15	7.30	8.89	8.68	6.87	7.34	7.64	7.77
Kentucky Supplemental	7.95	8.88	8.86	8.56		11.10	10.15	9.83	9.98	10.83	11.32	10.86	10.98	10.46	10.76	10.72
Kentucky Surplus		5.06	5.24		6.91	5.92	5.47	6.78	8.82		8.95		9.92	7.90	9.23	
Tennessee Surplus								16.1	14.9	16.4	16.9	17.4		17.0	15.9	16.9
Average: Main & Supplementals	8.28	8.84	8.27			10.93	9.89		9.90	10.52	11.19	11.00	10.44	10.19	10.51	10.57

Average 533 x Lob.	Average 546 x Lob.	Average 550 x Lob.
10.21	11.09	10.31

loblolly. In the twelve plots of hybrids the coefficient of variation ranges from 8 to 16 percent averaging 10 percent for the hybrids pond x 551. In the Kentucky supplemental test the coefficient of variation of the hybrids ranges from 10 to 17 percent, the two North Carolina Coastal loblolly lots are 15 percent, north Mississippi loblolly 22 percent, and the three pond pine lots from 17 to 26 percent. In general, in these two tests the hybrids are slightly more uniform than commercial loblolly, certainly a reasonable difference between plots of full-sib trees and unrelated trees. The uniformity of the hybrids further confirms the absence of any deleterious effects from hybridization that would be expressed as increased variability in growth.

RUST RESISTANCE

The two South Carolina tests are naturally infected intensely enough with fusiform rust (Cronartium fusiforme Hedgc. & Hunt ex Cumm.) to reveal differing degrees of resistance among the parent progeny and hybrid lines. Tree infection was scored on an index of increasing severity from 1 to 5 determined by gall position. In both tests pond pine is least infected, scoring 1.22 in the Coastal Plain and 1.07 with no stem galls in the Sandhills. Progeny of pond pine 533 are the most resistant. The North Carolina Coastal loblolly scored 1.67 in the Coastal Plain and 1.91 in the Sandhills. The high mortality of the North Carolina loblolly in the Sandhills could be expected to bias the score downward there. Piedmont loblolly having the best survival has the heaviest infection score of 2.57 with 39 percent of the stems cankered. Hybrids in the Coastal Plain are intermediate in infection with a score of 1.39 and are better than commercial loblolly in the Sandhills at 2.03.

In both tests the 533 x loblolly hybrids are most resistant indicating some influence from the pond pine parent. Hybrids pond x 551 are somewhat more resistant than hybrids pond x 544 in both tests. The particular hybrid cross 533 x 551 shows the overall best resistance in agreement with the better performance of the progeny of both the parents. Second best in resistance is hybrid 550 x 551 supporting the apparent better resistance of loblolly 551.

CONCLUSION

The hybrids as a group are intermediate between the parent lines in growth rate, rust resistance, and tip moth resistance. However, when removed to exotic and adverse sites the hybrid seems to be less sensitive to detrimental factors than loblolly pine and therefore predominates in growth, survival, and form. Thus, in the Sandhills hybrids pond x 551 exceed progeny of loblolly 551 and hybrid 546 x 544 grows as well as the Piedmont loblolly, and although its survival is 10 percent poorer its rust resistance is so much better that stand volume production might be expected to be better. In Kentucky where tip moth damage is severe on young loblolly pine the hybrids again are favored. Height of all hybrids is better than the customary commercial loblolly source for that region. Even on an exceptionally good site in Tennessee volume of the hybrids is equal to commercial loblolly. Height variability within the hybrid lots is slightly lower than in blocks of unrelated or half-sib trees. Hybrid progeny of particular pond x loblolly

cross pollinations reflect characteristics such as growth rate and rust resistance in a degree comparable to the pure progeny of the parent trees. The combination of desirable traits in three hybrid individuals has led to their recognition as having quality equal to that of loblolly pine trees selected for advanced generation breeding.

Whether the hybrid would provide an improved tree for pond pine sites is still essentially unknown. None of the test plantings could be made on the deep organic acid wet soils of eastern North Carolina that are native for the parent material. At those test sites where the hybrid growth was surprisingly good, its performance still appears to be within the range attainable through selection within loblolly pine alone.

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RESISTANCE OF SHORTLEAF X LOBLOLLY PINE HYBRIDS TO INOCULATION WITH FUSIFORM RUST

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Abstract.--A breeding program to recombine the high resistance of shortleaf pine to fusiform rust with the more rapid growth rate of loblolly pine has been initiated by the U. S. Forest Service in Macon, Georgia. Early results from progenies artificially inoculated with fusiform rust indicated that wind-pollinated progenies from F_2 hybrids were significantly more resistant than F_1 hybrids and F_2 hybrids backcrossed to loblolly, and that all three hybrid types were significantly more resistant than seed orchard loblolly clones. Early observations also indicated that some backcrossed hybrid full-sib families equalled or exceeded the height growth of the loblolly control.

Additional keywords: Backcross, progeny test, Pinus echinata, P. taeda, Cronartium fusiforme, recombine.

Hybridization between loblolly pine (Pinus taeda L.) and shortleaf pine (P. echinata Mill.) as a method of obtaining resistance to fusiform rust Cronartium fusiforme Hedgc. and Hunt ex Cumm.) has already shown some promise (Henry and Bercaw 1956). Better still, Sluder (1970) showed that certain shortleaf x loblolly hybrid combinations could combine very high rust resistance with high volume per acre due to good growth rate and high survival.

The present study comprises the full-sib progenies of F_2 shortleaf x loblolly hybrids backcrossed to progeny tested seed orchard loblolly clones, the progenies of wind-pollinated F_2 hybrids, F_1 hybrids, and a bulk lot from a loblolly seed orchard as a control. The hybrids were compared with the loblolly control in a test of their resistance to fusiform rust by means of artificial inoculation. This study is a portion of a new advanced-generation hybrid breeding program.

MATERIAL AND METHODS

The material consists of the following four groups: (1) F_1 hybrids; (2) the progeny of wind-pollinated F_2 hybrids; (3) the progeny of F_2 hybrids backcrossed to loblolly; and (4) the progeny of wind-pollinated seed orchard loblolly clones.

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The F_1 hybrids are the progeny of a cross between a selected and progeny tested shortleaf parent and a loblolly seed orchard clone (Group 1 in table 1). The shortleaf parent, Z15, is located in Harris County, Georgia and is included in a clone bank in the Whitehall Forest at Athens. Z15 was selected for resistance to littleleaf disease (Phytophthora cinnamomi Rand.), and progeny tests have shown it to have superior growth rate compared to other selected shortleaf families (personal communication, Dr. Charles R. Berry).

Table 1.--Seedlot and group means for height, diameter, percentage of trees with galls and gall volume

Groups and seedlots in groups	Height	Diameter	Trees with galls	Gall volume
	mm	mm	Percent	mm^3
Group 1 (F_1 Hybrid)				
Z15 x 541	138	2.7	42	58
Group 2 (F_2 x Wind)				
HH8 x Wind	170	2.9	7	138
HH15 x Wind	129	2.4	30	162
Group mean	150	2.6	18	150
Group 3 (F_2 x Loblolly)				
HH19 x 624	138	2.0	24	41
HH17 x 518	162	2.9	44	158
HH17 x 541	170	2.8	44	126
HH15 x 541	125	2.2	44	87
HH8 x 600	174	2.6	47	87
HH8 x 520	166	2.6	63	83
HH13 x 518	146	2.7	66	132
HH6 x 617	153	2.4	69	135
Group mean	154	2.5	50	106
Group 4 (S.O. Loblolly x Wind)	153	2.7	86	251

The second group of hybrids consists of seedlings derived from wind-pollinated seed collected from two F_2 hybrid trees (Group 2 in table 1). The F_2 hybrid trees are two of 40 hybrid trees selected on a one-acre block on the Hitchiti Experimental Forest. These "Hitchiti Hybrids," which comprised one of several hybrid types reported on by Sluder (1970), are the wind-pollinated offspring of crosses between a North Carolina shortleaf source and a Virginia loblolly source. The F_1 hybrid parents of the F_2 hybrids were produced at the

Institute of Forest Genetics in Placerville, California. The F_1 trees were allowed to cross-pollinate among themselves at Placerville to produce the F_2 seed, so that there was no possibility of contamination from other shortleaf or loblolly pine.

When the F_2 block on the Hitchiti Forest was measured in 1971 at age 20, the trees had virtually no fusiform rust, in contrast to the loblolly trees in the surrounding heavily infected natural stands. Six F_2 hybrid trees selected for good size and form were backcrossed to six seed orchard loblolly clones to produce eight seedlots (Group 3 in table 1). The half-sib progenies of the seed orchard loblolly clones had been shown to have good growth rate.

The loblolly control consists of the progeny of a random sample of wind pollinated clones from the Arrowhead Seed Orchard of the Georgia Forestry Commission (Group 4 in table 1).

In December, 1973 the seeds were germinated in the laboratory and transplanted into plastic containers measuring 13" x 5" and 4.5" deep in Macon. Twenty seedlings were planted into each container in two 10-seedling rows. Each 20-tree container represented one plot, and each seedlot was replicated four times. When the seedlings were 8 weeks old, they were transferred to Athens, Georgia, where they were inoculated by the Fusiform Rust Research and Development Program of the Southeastern Forest Experiment Station.

The seedlings were returned to Macon in late August and measured in September. Measurements made were: (1) height; (2) basal diameter; (3) presence of fusiform rust galls; (4) gall length; and (5) gall diameter.

The variables analyzed were: (1) height; (2) diameter; (3) arcsin $\sqrt{\text{percent}}$ of trees with galls; and (4) the logarithm of gall volume. Gall volume was calculated by subtracting the volume of the stem cylinder estimated to be within the gall, so that only the swelling of the stem due to the gall was analyzed. Gall volume was used to obtain some measure of resistance to severity of infection.

A good gauge of the overall severity of this inoculation test is the percentage of trees with galls of group 4, the loblolly control (table 1). This figure of 86 percent is typical of many 3-year-old progeny test plantations of loblolly pine studied by the authors in the Lower Piedmont and Upper Coastal Plain of Georgia.

The experimental design was completely randomized. Differences between groups and seedlots within groups were planned orthogonal comparisons. Differences were tested for statistical significance, and the results of those tests are shown in table 2.

Table 2.--Mean squares and significance of differences of orthogonal comparisons

Source	Degrees of freedom	Mean squares[a/] Height	Diameter	Trees with galls	Gall volume
Among lots	11	1,119.58*	505.24**	770.68**	0.184**
Groups (1) vs. (2)	1	322.67	28.17	713.95**	.451**
Within Group (2)	1	3,280.50*	840.50**	667.95**	.009
Group (3) vs. Group (4)	1	3.12	205.03	1,886.00**	.591**
Groups (1) + (2) vs. Groups (3) + (4)	1	650.25	169.00	2,935.83**	.002
Within Group (3)	7	1,151.27*	616.42**	324.82**	.138*
Within lots	36	492.74	101.31	59.24	.049
Total	47				

[a/] * Significant at 5% level.
** Significant at 1% level.

RESULTS AND DISCUSSION

Group 4, the seed orchard loblolly control, had the highest percentage of trees with galls and by far the greatest gall volume of any group (tables 1 and 2). Moreover, the mean height of Group 3, the F_2 hybrids x loblolly, was essentially the same as that of Group 4, the loblolly control.

Certain specific comparisons of interest were not tested statistically. Group 1 seedlings, the F_1 hybrids, were 15 mm shorter than those in Group 4 on the average. This difference was expected. Assuming no heterosis, F_1 shortleaf x loblolly hybrids will probably be intermediate in height growth between shortleaf and loblolly.

Since the crosses in Group 3 represent a third generation of hybrid breeding, they offer the best opportunity to evaluate the possibilities of recombining growth rate with rust resistance. Four of the progenies of Group 3 exceeded the mean height of Group 4 (table 1). If these differences are real,

then some hybrids can be expected to grow faster than loblolly. But even if the differences occurred by chance, we still have good growth rate in hybrids that are significantly superior to loblolly in rust resistance. In fact, two of the four Group 3 progenies having better height growth than the loblolly control also have low percentages of trees with galls and very low gall volumes. Although it is too early to be certain that these differences are reliable evidence of segregation for growth and resistance traits, there is some basis for believing that inoculation test results will accurately predict relative rust resistance in the field. Dinus (1972) found very close correlations between artificial inoculation and field infection of six half-sib slash pine (P. elliottii Engelm.) families. Rankings among families changed very little between inoculation tests and field tests. The large variation among hybrid types for rust resistance in the present tests suggests that these rankings will remain relatively unchanged in the field.

Of the hybrid types, the wind-pollinated progenies of F_2 hybrids (Group 2) had significantly fewer trees with galls but greater gall volumes than the F_1 hybrids of Group 1 (tables 1 and 2). Evidence of increased rust resistance is probably to be expected in the Group 2 wind-pollinated hybrids. Observed flowering times in most of these hybrid trees overlap more with shortleaf than with loblolly flowering times. Further, Hicks (1974) has found evidence in suspected shortleaf x loblolly hybrids that backcrossing among natural hybrids in east Texas is probably more in the direction of shortleaf than of loblolly. Although gall volumes were larger in Group 2 than in Group 1 or 3, they were still much smaller than the loblolly control.

Differences within Group 2 and Group 3 were significant for all traits except for gall volume in Group 2. The variability in Group 3 suggests considerable specific combining ability among hybrid crosses.

CONCLUSIONS

This initial study demonstrates the potential use of advanced-generation hybridization among southern pines. It suggests that resistance to fusiform rust may be transferred from shortleaf into the loblolly pine genome without reduction in growth. In fact, some backcrosses of F_2 hybrids x loblolly exceeded the height growth of the seed orchard loblolly control.

It goes without saying that continued observations of the rust resistance and growth rate of these hybrid types in the field will be needed to fully evaluate the possibilities of an advanced generation hybrid breeding program. All of the seedlots which comprised the present inoculation test have been included in a larger field progeny test. This field test also includes additional hybrid crosses in all groups, a loblolly commercial check, and two shortleaf provenances. Other field progeny tests with new hybrid material are also being prepared. Hence, in three to five years we will begin to obtain data which will confirm or refute the present results.

These promising early results should encourage breeders to establish more plantations of shortleaf x loblolly hybrids. Continued selection and backcrossing should ultimately produce trees which combine the rapid growth rate of the best loblolly pines with the high rust resistance of shortleaf pine.

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THE EFFECT OF SEED ORIGIN ON SEED WING MORPHOLOGY AND JUVENILE GROWTH OF EAST TEXAS GREEN ASH

R.A. Woessner and Van Hicks, Jr. [1/]

Abstract.--Morphological measurements were made of green ash seed wing characteristics on a sample of seeds collected from 185 trees growing in the Pine-Hardwood and the Post-Oak forest regions of Eastern Texas. Seed wing width of seeds of the middle and southern areas of the Post-Oak forest was greater than that found in other regions of East Texas. The widest seeds were collected near the "Lost Pines" forests of Eastern Texas. Seedlings were grown from the same seedlots and then used to establish plantations of half-sibs in northern and southern East Texas. One-year height measurements made in four different plantations indicated that there was a trend for growth to increase as the source of the seed moved south and west. These preliminary results indicate that further research is warranted to determine if other hardwood species from the "Lost Pines" area possess growth or other physiological characteristics such as drought resistance which could be exploited in a tree improvement program.

The seed wing morphology and one-year height of green ash Fraxinus pennsylvanica Marsh. collected from 41 seed origins in Eastern Texas were examined in this study. Many previous authors have studied variation patterns in phenotypic morphological characteristics since they may indicate the existence of genetically controlled characteristics that can be exploited in a tree breeding program. Thorbjornsen (1961) studied the variation patterns in natural stands of loblolly pine Pinus taeda L. throughout most of its natural range and found good evidence of regional variation patterns in fruit, seed, and needle characteristics. Wells and Wakeley (1966) found geographic variation in survival, growth, and fusiform-rust infection of loblolly pine. A North Carolina study of yellow-poplar Liriodendron tulipifera L. by Kellison (1967) revealed the existence of a distinct acid soil ecotype which differed from other populations in foliage, seed, and wood properties. The seeds were distinctive in that the samaras were long and narrow. A later study with the same species (Kellison, 1970) showed that the acid soil ecotype also had distinctive growth and survival properties. Seed origin was shown to have an effect on the drought resistance of green ash by Meuli and Shirley in 1937. Drought resistance in the Prairie-Plains states increased from south to north and from east to west. Foliage color, seed germination rate, growth rate, and tree dormancy were found to be associated with the drought resistant characteristic.

MATERIALS AND METHODS

The seeds used in this study were collected from individual trees from

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[1/] This research was done when the authors were employed by the Texas Forest Service, College Station, Texas, as Associate Geneticist and Hardwood Silviculturist respectively. Their employer now is National Bulk Carriers, Inc. 1345 Avenue of the Americas, New York, N.Y., 10019, Attn: Jari Project.

stands located throughout the East Texas Pine-Hardwood forest (31 stands) and the Post-Oak forests (10 stands) during the fall season of 1970 and 1971. The outline map (fig. 1) shows the approximate location of the 41 stands. From three

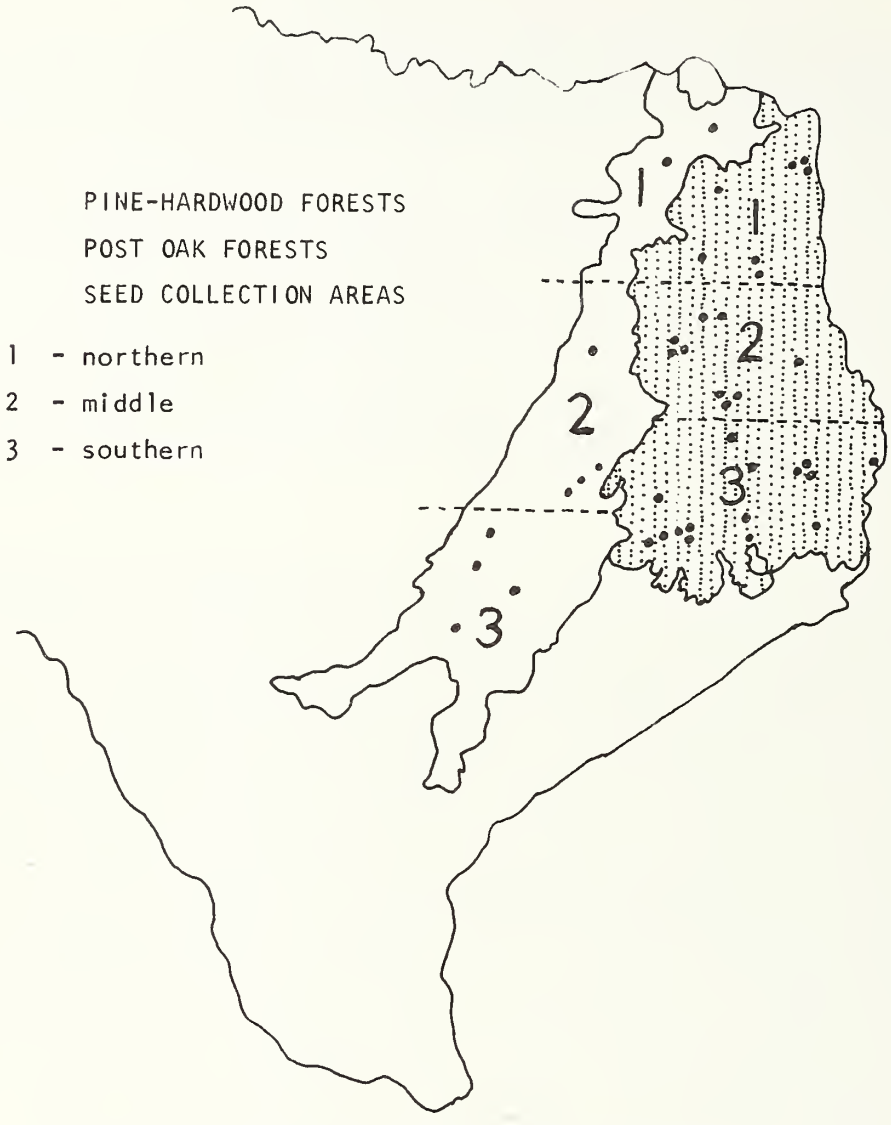


Figure 1.--Green ash seed collection areas in Eastern Texas.

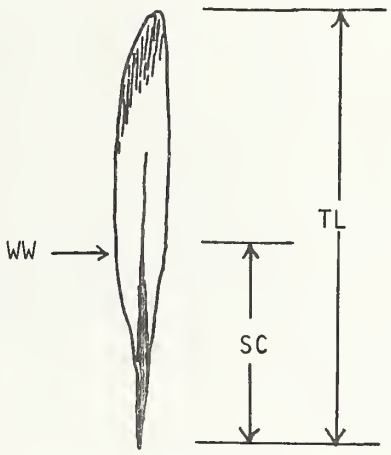
to seven individual trees per stand were collected with five trees per stand being most frequent. Forty-five trees were collected in the Post-Oak forest region and 140 trees were collected in the Pine-Hardwood forest region (table 1). From 250 to 900 grams of seed were collected per tree. The seeds were air dried

at room temperature. A ten seed random sample of unbroken seeds were selected to be measured for each of the 185 trees. Three linear measurements were made on the 10 seed sample to the nearest hundredth of an inch. The measurement variables were total samara length, samara width at the distal end of the seed cavity, and seed cavity length (fig. 2). A fourth variable was derived by dividing samara width by total length since ratios may be better than the actual measurements in indicating relative differences.

Table 1.--The number of stands and trees sampled

	Pine-Hardwood				Post-Oak			
	North	Middle	South	total	North	Middle	South	total
number of stands	7	9	15	31	2	4	4	10
number of trees	33	42	65	140	8	20	17	45

Seedlings were raised from the seedlots and four half-sib plantations were established in East Texas in a northern and southern location in 1972 and 1973. In 1972, duplicate plantations were planted in Harrison and Montgomery counties. In 1973, duplicate plantations were planted in Cherokee and Montgomery counties. Sufficient seedlings were not obtained from all seedlots to establish outplantings of all the trees that were collected. Some families were also common to the 1972 and 1973 plantations. The basic planting design was a randomized complete block of six replications. Four tree plots were used and the spacing was 3 meters by 3 meters. The plantations were disked to control competing vegetation. Height measurements were made after the first growing season.



TL - TOTAL LENGTH

SC - SEED CAVITY LENGTH

WW - WING WIDTH

Figure 2.--Illustration of the seed wing measurements

The mean of the 10 seed sample and the mean of the four tree plots were subjected to an analysis of variance. A nested analysis was used assuming a random model. Areas, stands within areas, and trees within stands were the sources of variation for the seed characteristics. The sources of variation for the height analysis were replications, areas, and trees within areas. Several stands had only one collection tree represented. Because of this, trees within areas was used as a source of variation rather than stands within areas and trees within stands within areas.

Means were computed for the three areas of the Pine-Hardwood and the three areas of the Post-Oak forests as shown in fig. 1.

RESULTS

Analysis of variance results for the seed wing characteristics (table 2) indicate significant differences among areas for wing width and the ratio of

Table 2.--Analysis of variance results for the four seed characteristics and one-year height growth[a]

Source	df	Seed Characteristics 'F' Test Results			
		total seed length	seed cavity length	wing width	wing width/ total length
areas	5	ns	ns	.05	.05
stands in area	35	.05	.05	.05	ns
trees in stands	144				

Height Growth

1972 Plantations

Source	Harrison County df	Harrison County 'F'	Montgomery County df	Montgomery County 'F'
areas	4	.10	4	.10
trees in areas	46	ns	45	ns
error	194		203	

1973 Plantations

Source	Cherokee County df	Cherokee County 'F'	Montgomery County df	Montgomery County 'F'
areas	5	.05	5	.10
trees in areas	113	ns	108	ns
error	423		394	

[a] ns not statistically significant at the .05 level.
.05 statistically significant at the .05 level.
.10 statistically significant at the .10 level.

wing width to total seed length. Examination of the area means (table 3) of wing width and the ratio of wing width to total seed length for the northern, middle, and southern areas of the Pine-Hardwood and the Post-Oak forest regions

Table 3.--Mean values in cm of the green ash seed characteristics and mean values for height in cm by areas of the Pine-Hardwood and Post-Oak forests of East Texas

	Pine-Hardwood			Post-Oak		
	North	Middle	South	North	Middle	South
total seed length	3.4	3.4	3.5	3.7	3.5	3.5
seed cavity length	1.6	1.6	1.6	1.7	1.6	1.7
wing width	.37	.40	.40	.39	.47	.51
wing width/ total length	.28	.30	.30	.27	.35	.37
			Height Growth			
1972 Plantations						
Harrison County	52	63	67	-	59	79
Montgomery County	60	69	66	-	68	84
1973 Plantations						
Cherokee County	85	87	94	73	104	94
Montgomery County	66	80	90	66	73	74

of East Texas reveals an interesting pattern of variation. The middle and southern areas of the Post-Oak forest have seeds with much wider samaras. Wing width averages .49 cm in the middle and southern areas of the Post-Oak forest and .39 cm in the rest of Eastern Texas. The trend within the Post-Oak forest region is for an increase in wing width from north to south, .39 to .51 cm. A similar trend exists in the Pine-Hardwood forests although the differences among the area means are not nearly so large, .37 to .40 cm. A better appreciation of the distinctive appearance of these seeds from the middle and southern Post-Oak forests can be obtained from figures 3 and 4. One representative seed from each of 5 trees from each area of both forest regions is pictured.

Analysis of variance results for one year height (table 2) indicate significant differences among areas in all four plantations. Examination of the area means (table 3) indicates that tree height has a tendency to increase as you go

south in either the Pine-Hardwood or the Post-Oak forests. The trend for height is not as clear cut as for wing width since the middle and southern areas change ranks several times. The mean height of the two northern areas do average 16 percent less than the average for the two middle and southern areas.

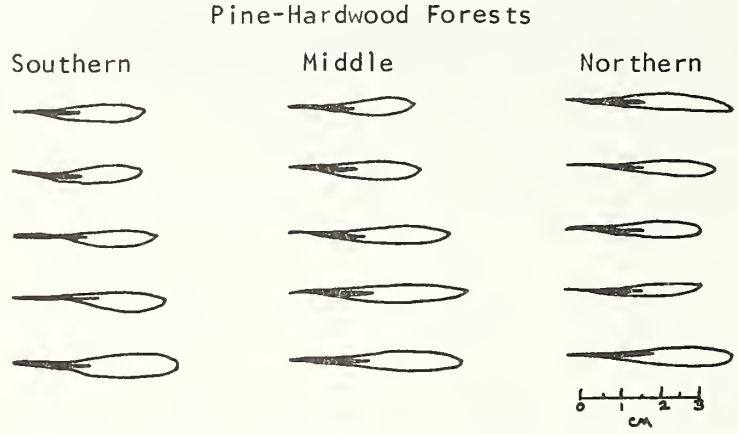


Figure 3.--Sample of seeds from the Pine-Hardwood forests. One seed from each of 5 trees from each area.

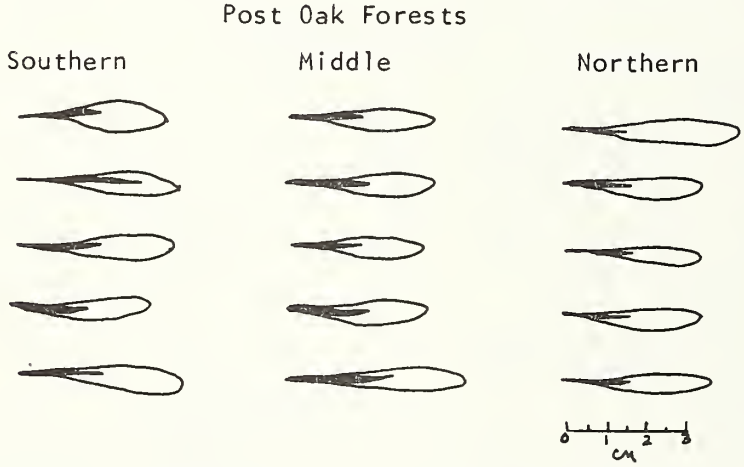


Figure 4.--Sample of seeds from the Post-Oak forests. One seed from each of 5 trees from each area.

Stand differences in areas are indicated for total seed length, seed cavity length, and wing width (table 2). However, differences among trees within areas were not shown to be significantly different in the analysis of the one-year height data. There could be significant stand-to-stand differences for height. The inadequacies of this data precluded making such an analysis. Stand-to-stand differences have frequently been found in hardwood species. Schmitt and Webb (1970) in reviewing studies of natural variation in hardwood species stated that a significant portion of the variation of hardwood species is associated with stands.

DISCUSSION

These results with green ash indicate genetic differences among populations

just as did the work of Meuli and Shirley in 1937. The distinctive appearance of the seeds from the southern portion of the Post-Oak forests and the possibility that such populations may possess other desirable characteristics is particularly interesting because they were collected near the "Lost Pines" forests of Texas. These "Lost Pines" consist of several islands of loblolly pine growing between 100 miles and 130 miles west of the western edge of the southern pine belt under conditions of low rainfall. The morphological structure of their needles differs from other loblolly pines (Thames, 1963). The Texas Forest Service has found the "Lost Pines" superior to other loblolly pines in drought resistance (Zobel and Goddard, 1955). McClurkin, et al. (1971) found the potassium-calcium ATPase system in the "Lost Pines" to be completely different than that found in root tips of other loblolly pines. The factors which have led to the formation of genetic seed source differences in loblolly pine in the "Lost Pines" area could have had the same effect on other Texas tree species. For example, one-year heights of water oak families indicated that oak originating from the southern parts of East Texas will grow faster than those from the northern part of East Texas. Sycamore growth results did not indicate a clear cut north-south or east-west gradient, but source was important (22nd Progress Report of Cooperative Forest Tree Improvement, 1974). Nurserymen have noticed a tendency for sycamore that is collected from the Post-Oak belt to be more resistant to leaf scorch during the summer months as compared to other sources.[2] Of the Texas species studied so far, sweetgum is the only one which does not show source differences. It is also the only species so far studied that does not extend its range into the Post-Oak belt. Ideal conditions for genetic differentiation exist since the populations growing in the Post-Oak belt tend to be scattered and isolated. However, they are not completely isolated. Desirable gene combinations stabilized here could on occasion be transferred to populations in the Pine-Hardwood area. The results with green ash certainly indicate that more intensive research is warranted in order to better determine if hardwood species from the "Lost Pines" area or areas adjacent to it possess characteristics which could be useful in a tree improvement program.

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DEVELOPING A SAMPLING METHOD TO DETERMINE EFFECTS OF INSECTS ON YIELDS IN SOUTHERN PINE SEED ORCHARDS

Carl W. Fatzinger, Gerard D. Hertel, Edward P. Merkel, and F. Thomas Lloyd[1/]

Abstract.--Describes objectives and current activities of a Seed Orchard Sampling Committee. Cooperating members of the committee are conducting sampling studies on five pine species in seven southern states. Duration of the studies is three years and results will be used to estimate impact of various destructive agents on orchard seed yields. Life tables for the pine cones of each pine species will be constructed for use in developing seed yield prediction models. Current partial results of the studies are presented.

During a Seed Orchard Sampling Workshop held at Olustee, Florida, on November 1 - 2, 1972, representatives of State and Federal Forest Services, universities, and private industry agreed that a suitable sampling method for determining the impact of insects on southern pine seed orchards was lacking. The Seed Orchard Sampling Committee was formed to develop such a method; members were from the Southeastern Forest Experiment Station, State and Private Forestry, the Texas Forest Service, the Louisiana Forestry Commission, and Mississippi State University. The purpose of the sampling will be to estimate the impact of various destructive agents, including insects, on seed orchard yields. Monthly observations taken during cone development will be used to construct life tables for use in developing seed yield prediction models. The results of the study will also be used to develop sampling methods for evaluating the effectiveness of different insect control measures.

To fulfill these objectives in a reasonably short time, a sampling method was arbitrarily selected for obtaining initial observations. The same basic method is being used for collecting these initial observations in the study orchards, and the results will be compiled and analyzed by similar methods at one location.

The study will take 3 years and will include two successive crops of cones from each of the study orchards. A total of 11 studies in 8 seed orchards are underway. Orchards of slash pine, loblolly pine, shortleaf pine, longleaf pine, and Virginia pine, in Florida, Mississippi, Louisiana, Texas, Arkansas, Tennessee, and North Carolina are represented.

A population of clones was selected within each of the study orchards. Initially, each investigator determined the number of clones he could sample in his orchard. Inferences, therefore, can only be made for those clones selected and may not apply to the entire orchard unless all clones within the orchard were included in the sample. Two or more ramets from each clone

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were selected at random, and a random sample of 10 percent of the conelet clusters on each ramet was tagged. Each bud within the cluster was also tagged to identify the individual structures throughout the study. Cones were observed monthly, and the causes of damage and mortality were recorded. At cone maturity, seeds will be extracted by techniques that maintain the individual records of each cone.

Seeds will be radiographed to determine losses caused by seedbugs, seedworms, and other factors. They will then be germinated to determine the number of viable seeds per cone. Results will enable us to relate seed yields to the developmental history of each cone.

The initial phase of this study will be completed in the fall of 1976. Results of the different samples will be analyzed and compared to determine the possibilities of devising practical sampling methods for the different species of pines represented in the study.

We recently completed the analysis for one crop of slash pine cones sampled in the McColskey Still Seed Orchard near Lake City, Florida. This study was initiated 1 year prior to the other sampling studies to try out the observation methods. The results indicated that 53.2 percent of the ♀ buds in the orchard did not mature into cones for collection in the fall. Insect attacks accounted for about 35 percent of this loss, but causes for the other 18 percent loss are unknown. In addition, only 53 percent of all seeds germinated. Forty-seven percent of the seeds were insect attacked, empty or malformed, not extracted, or not viable. The total loss of potential seed for the McColskey Seed Orchard was about 72 percent when measured from the flower bud stage throughout the procurement of viable seeds. Thus, in the absence of insect control, only about 28 percent of the potential seed yield was harvested from this orchard.

Analyses for the first crop of cones in the other study orchards will not be made until this winter. Loss estimates during the first 5 to 6 months of these studies, however, have ranged from 15 to 84 percent of initial buds.

PLANT PATHOGENIC MICROORGANISM MAY BE REDUCING CONE PRODUCTION IN SEED ORCHARDS

Thomas Miller and D. L. Bramlett[1/]

Female flowers of both slash (Pinus elliottii var. elliottii Engelm) and loblolly (P. taeda L.) often die during the period from just before the flowers become receptive to about three weeks after pollination. We think there is a strong possibility that pathogenic microorganisms, especially fungi, may be involved, and we are studying the situation.

This year we have collected flowers and conelets of different damage classes from both slash and loblolly pines in the Arrowhead Seed Orchard. We isolated a variety of fungi from these dead or damaged strobili which we are identifying and maintaining in culture for future inoculation experiments. Flowers and conelets with different symptoms have been collected and are being examined histologically. Pollen is also being examined for contaminating microorganisms.

In some preliminary experiments this year, we have produced damage symptoms on loblolly flowers by inoculating with fungi isolated from damaged flowers of slash pine.

A full-scale study will be required to estimate the impact of microorganisms in seed orchards. We are planning such a study for next year.

[1/] Southeastern Forest Experiment Station, Fusiform Rust Research and Development Program, Athens, Georgia, and Breeding Southern Pines Project, Macon, Georgia.

EFFECTS OF FERTILIZER TREATMENT APPLIED TO A YELLOW-POPLAR "SEED ORCHARD"

Franklin C. Cech, Roy Keys and James Brown1/

Abstract.--Height, diameter, and seed head production were analyzed after six years of biannual fertilizer, lime, and herbicide applications on a yellow-poplar seed orchard.

Thinning was found to increase diameter growth, live crown length, and seed head production. Trees in unthinned areas showed greater height growth, probably due to less wind damage on these plots. Herbicide application increased height and diameter growth. And the application of nitrogen at 150 and 300 # per acre resulted in increased seed head production. Inconsistency in seed head production shows that genetic potential for productivity will have as much or more effect than environmental manipulation.

It is recommended that wide spacing and the application of nitrogen fertilizers be used to establish trees with good seed production.

Additional Key Words: Seed production.

Several orchards for the production of superior yellow poplar seed have been established and others are in the planning and establishment stages (anonymous 1971). Normal seed bearing age for yellow poplar has been reported to be as young as 9 years (Schopmeyer, 1974). Where orchards are established by grafting mature yellow poplar clones, early seed production should result. However when seedling seed orchards are established, some technique is needed to stimulate early seed production. Further, techniques are needed to achieve and maintain full seed production as a part of seed orchard management. There is little or no information covering management procedures for yellow poplar seed orchards.

This study was designed to investigate the effect of thinning and fertilizer application on seed production and growth of yellow poplar of sapling size at a final spacing of approximately 36 by 36 feet.

1/ Professor, Forest Genetics and Research Technician, Forestry, West Virginia University, Morgantown, West Virginia and Professor, Ohio State University, Ohio Agriculture Experiment Station, Woostor, Ohio.

The study was established on a 7 acre portion of a 9 year old plantation owned by the Kaiser Aluminum and Chemical Corporation near Ravenswood, West Virginia2/. The area had been machine planted on a 6 by 6 foot spacing. Survival had been excellent and a full stand was established. Trees averaged 21.7 feet in height and 3.5 inches dbh.

Soils are of the Muskingham Upshur series, well drained with an approximate site index of 55 to 64 for oak (Anonymous 1961).

In 1966 the plantation was thinned to an approximate 12 by 12 foot spacing, removing, wherever possible the poorest trees. One year later a second thinning was made to approximate a 36 by 36 foot spacing; this being the projected spacing for a yellow poplar seed orchard. In spite of the fact that severe winds are often encountered in this area, there was no wind-throw after either thinning. Control trees were selected in the unthinned stand on the periphery of the area and all trees were permanently numbered. Soil samples were taken around each tree and bulked by treatment for analysis. Treatments to be applied were high (300# per acre), medium (150# per acre) and low (0# per acre) of N, P and K in a factorial design using all possible combinations of these elements. Three additional treatments were included as special controls: 1. Thinning only, 2. Thinning plus lime and 3. Thinning plus herbicide. Treatments were applied to two tree plots as a measurement unit. Prior to the application of the fertilizer, all treatment plots except as previously noted were sprayed with Amizine at the rate of 10# per acre in an area of 8 foot radius around each tree. The average pH of the area was approximately 6.4 and lime was applied to all trees except as noted previously at the rate of three tons per acre (20# per tree) in an area with an 8 foot radius around each tree.

Treatments were assigned in a completely randomized design with five replications and fertilizer applied three weeks after the lime application, in late May.

Based on soils analyses, fertilizer and lime amendments and herbicide applications have been made biannually after the initial treatment.

After six years, the average height of the trees is 39.5 feet and average dbh is 9.98 inches. The average number of seed heads produced per tree is 337. Height variation is from 46.0 for the untreated control to 36.7 for treatment 29 (thin only). The largest average diameter

2/ The authors wish to thank the Kaiser Aluminum Corporation for the use of the plantation and their continued cooperation in carrying out the study.

is 11.0 inches dbh in treatment 12 (medium N, low P, high K), while the smallest average diameter is 6.58" for trees in the unthinned control. Greatest seed head production is from treatment 11 trees (medium N, low P, and medium K), an average of 615 per tree while the smallest production is from the unthinned control, an average of four seed heads per tree (See Table I).

The analysis of variance with all treatments using only growth from 1972-73 showed no significance for height, very high significance for diameter growth and no significance for seed head production.

Treatment-control comparisons show that differences due to "thinning alone" are significant at the 5% level for all three variables; for "lime alone" they are significant at the 5% level for height. Differences due to "herbicide alone" are significant at the 5% level for height and diameter; and for all fertilizer treatments combined, they are significant at the 5% level for diameter and seed head number (See Table II).

The number of trees producing seed has increased from 9 (2.8%) to 293 (94.2%) since the first treatment. Of the 17 non producing trees, 10 are in the unfertilized controls, 6 in the low N treatments and one in the medium level for N, P and K. One fourth of the unfertilized trees are not bearing seed at this time.

DISCUSSION

Although the thinning operation was planned mainly to approximate seed orchard spacing, control trees in the unthinned area were selected to establish a base for treatment response. Of interest is the fact that the greatest response in both diameter growth and seed head production was associated with thinning.

The tree crowns in the thinned area have increased in diameter and live crown length, most of the trees having live branches to within four or five feet of the ground.

Yellow-poplar is apparently a species which responds well to thinning even at an advanced age. Beck and Della-Bianca (1975) showed that stands up to 70 years of age responded well to heavy thinning. Our results would certainly support the fact that thinning at early ages can also be beneficial.

Height growth in the unthinned area was better than in thinned areas regardless of treatment. This is confounded by the fact that there has been continued branch breakage in the thinned area. Exactly how much this has affected the current height measurement in problematical, but there is no doubt that a bias has

been introduced because of this fact. There is evidence that more breakage occurs on trees in the heavier fertilizer treatment (Cech et. al. 1975).

The Amizine application was designed to minimize fertilizer uptake of herbaceous competition in the fertilized areas. Fitzgerald and Seldon (1975) reported an increase in height growth of yellow-poplar, three years after transplanting. The results of our study support this fact and also show an increase in diameter growth with repeated application of herbicide. Though statistically nonsignificant, there is also marked increase in seed head production in plots which were thinned and herbicided over those which were thinned only.

The addition of Nitrogen at either level resulted in an increase in diameter growth which was not statistically significant, and an increase in the number of seed heads which was statistically significant at the 5% level. There was no significant effect from P and K for the 1974 seed crop.

One of the problems in analysis is the inconsistancy of seed production within treatments. In one case one of two pairs of trees had 2,304 seed heads while the paired tree (with the same treatment) had 14 seed heads. Several trees bore over 1,000 seed heads. Often one very productive tree offsets the low production of the other trees in the treatment. Apparently the genetic potential for productivity will have as much or more effect on seed production at the early age of 15 than the environmental manipulation tried in this study.

At this point, the only clear evidence, is that for thinning, and the beneficial effect of nitrogen application on diameter growth and seed head production.

Apparently wide spacing in seed orchards and application of nitrogen fertilizers will be sufficient treatment to establish trees with good seed production.

Table 1. Average height, diameter, and number of seed heads six years after initial treatment.

Treatment	N	P	K	1974 Height(Ft.)	1974 Diameter(In.)	1974 Number of Seed Heads
1	L	L	L	40.50	10.41	391
2	L	L	M	35.11	8.80	190
3	L	L	H	36.89	8.79	316
4	L	M	L	38.60	9.67	179
5	L	M	M	39.78	9.68	296
6	L	M	H	39.90	9.95	411
7	L	H	L	38.40	9.26	344
8	L	H	M	38.90	9.27	205
9	L	H	H	36.90	9.71	195
10	M	L	L	40.30	10.69	615
11	M	L	M	39.90	9.58	253
12	M	L	H	39.90	11.06	358
13	M	M	L	38.30	9.60	437
14	M	M	M	38.70	10.54	545
15	M	M	H	39.90	10.78	327
16	M	H	L	38.90	10.27	455
17	M	H	M	40.00	10.74	380
18	M	H	H	40.33	10.97	498
19	H	L	L	40.60	10.83	372
20	H	L	M	41.33	10.78	385
21	H	L	H	39.25	10.25	298
22	H	M	L	41.10	10.59	437
23	H	M	M	41.10	10.44	451
24	H	M	H	39.90	10.23	420
25	H	H	L	38.90	10.02	410
26	H	H	M	38.40	10.22	314
27	H	H	H	37.60	10.29	197
28	Herbicide only			40.20	10.45	352
29	Thin only			36.70	9.42	204
30	Lime only			41.60	9.48	220
31	Control			46.60	6.58	4
	Average			39.51	9.98	337

L - Low
M - Medium
H - High

Table 2. Treatment-control Comparison.

A. Modified LSD

Effect	Treatments Compared	Ht.	LSD	Significance	Diam.	LSD	Sign.	Number of seed heads	LSD	Sign.
	Thin	36.70	2.248	*	9.42	0.783	*	204	165	*
Thinning	No Thin	46.60			6.58			4		
	Thin	36.70	2.248	*	9.42	0.783		204		
Lime	Lime	41.60			9.48			220		
	Herbicide	40.20	2.248	*	10.45	0.783	*	352		
Herbicide	Thin	36.70			9.42			204		

B. Tukey Test

Effect	Treatments Compared	Ht.	LSD	Significance	Diam.	LSD	Sign.	Number of seed heads	LSD	Sign.
	Fertilized	39.24	3.173		10.13	1.105		358	232	
Fertilizer	Thin	36.70			9.42			204		
Fertilizer	Fertilized	39.24	3.173		10.13	1.105		358	232	
X Herb	Herbicide	40.20			10.45			352		
Fertilizer	Fertilized	39.24	3.173		10.13	1.105		358	232	
X Lime	Lime	41.60			9.48			220		
	Fertilized	39.24	3.173		10.13	1.105	*	358	232	*
Treatment	Control	46.60			6.58			4		

*Significant at the 5% level.

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SESSION III - INCREASING SEED YIELD

MODERATOR: ANTHONY E. SQUILLACE

INCREASING SEED YIELD THROUGH CULTURAL PRACTICES - TODAY AND TOMORROW

C. B. Davey [1/]

Abstract.-- Proper management of tree nutrition and moisture regime as well as the maintenance of good soil physical factors will result in increased seed yields from seed orchards. If careful site selection and preparation are conducted prior to orchard establishment, they will also pay dividends in seed yield obtained and in ease of orchard management.

Additional keywords: Seed orchard, site selection, soil, fertilization, irrigation, subsoiling.

Over the past decade and a half considerable progress has been made in increasing seed yield in Southern pine seed orchards through the development of improved and intensified cultural practices. These practices are important during orchard establishment and early vegetative growth as well as during the reproductive growth phase of the trees. These cultural practices have included improved tree nutrition through the use of fertilizers, improved tree moisture regime through seed orchard irrigation, and improved soil physical conditions and tree rooting habit through proper subsoiling of the orchard soil. Each of these practices has resulted in improved tree vigor and seed production. Also, they are compatable and their effects are partly additive. Much remains to be done in the area of delineating optimum utilization of each.

This paper includes a very brief summary of the development of these practices up to 1975 and includes some thoughts and speculation on further increasing seed orchard seed yields over the next few years. Throughout this paper megasporangiate and microsporangiate strobili are referred to as female and male flowers, respectively. Hardwood seed orchards are not included in this discussion in part because they currently represent only a small acreage in comparison to the pines and secondly, because research on increasing seed production in them is only now gaining momentum.

TREE NUTRITION

It had been intermittantly reported in the literature for about four decades that well-nurished trees in natural stands and seed production areas produced more seed than did trees on a more stringent diet (Gemmer 1932). Beginning in the early 1960's, however, the question was being asked whether this same concept would also apply to grafted "superior" trees in seed orchards. The answer was not immediately obvious.

The history of seed orchard fertilization has progressed in a step-wise manner. The early trials simply tested whether fertilization (sometimes in

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combination with irrigation) would stimulate flowering and seed production. The answer was usually in the affirmative. The second generation of tests involved the determination of which nutrients were usually the most critical in terms of stimulating flowering and seed production. These tests provided information suggesting that on most soils in the South, phosphorus and, on essentially all soils, nitrogen were needed. The third generation of tests then included studies of different rates of application of nitrogen and phosphorus.

Each of these sets of tests have had to span five or more years since it is the third year before the harvested cones have been under the influence of the imposed treatment throughout their development. Then at least two more years are required to account for year-to-year climatic variation.

It was learned early that there is always tree-to-tree variation within the ramets of the same clone. This led to the general conclusion that a minimum of five ramets of each of five clones was necessary per treatment plot. Then a minimum of three replications per treatment resulted in the inescapable conclusion that few if any existing seed orchards are large enough to provide for complete factorial designs which cover more than a very few treatments. This has led to the utilization of incomplete rotatable factorial designs with replication restricted to the central treatment and similar statistical shortcuts.

At this point in time, it is safe to say that proper fertilization is worthwhile and is probably essential in nearly all seed orchards, if their seed-producing potential is to be even closely realized. Nitrogen has been repeatedly shown to be the key element in stimulating flowering and seed production.

The effect of fertilization has been the production of more branches on a tree, more flowers per branch, and increasing the portion of the tree crown which bears flowers (Webster 1974). The biggest single effect of fertilization appears to be the stimulation of a large number of bud primordia to differentiate into either flower or branch buds rather than needle fascicles (Webster 1974).

To date fertilization has not been shown to greatly reduce the time required to bring an orchard into meaningful production or to markedly reduce the number of unproductive clones. In every test known to this author, there has been a greater range in seed production among clones than there has been among treatments.

The next areas of interest in fertilization research should shed light on the matters of the impact of nutrient form and time of application on tree flowering and seed production. We expect to hear about current research on both of these topics today. Eventually we will need to study nutrient balance within the tree. This information will lead to a more efficient fertilization program than is now possible.

SOIL FERTILITY

Knowing that trees can respond to fertilization is only a portion of the solution to the problem. Of equal importance is being able to determine nutrient needs. This can theoretically be approached through either or both soil testing or tissue analysis. To date, neither system is fool-proof but more progress has been made in utilizing soil testing than tissue analysis to predict nutrient needs. The following standards are currently used for determining nutrient needs where the dilute double acid soil extractant is used. This includes the majority of the states in the South.

Soil attribute	Units	Desired level
P	lbs/acre 1/	40
K	"	150
Ca	"	400
Mg	"	50
Mn	"	10
Acidity	pH	5.5
Organic Matter	%	2.0

1/ Also approximately kg/ha

In all soils the amount of a nutrient needed to raise its test value from that determined to that desired exceeds the difference in the two values. The finer the soil texture, the greater the application needed. Also, seed orchards in the Piedmont require larger applications of phosphorus than do those of the Coastal Plain.

The major element nitrogen is not included in the above chart since there is no test for available soil nitrogen. It has been generally established that within reason, nitrogen needs can be determined from the percent organic matter in the soil, the soil type, and the age of the trees to be fertilized. Additional research in this area is needed, however.

Nitrogen is important at all stages of seed orchard management. An adequate supply of nitrogen will increase grafting success during orchard establishment. This can be obtained from about one ounce (30 gm) of elemental nitrogen per tree applied once in the month or two immediately before grafting as well as during the preceeding year.

During vegetative growth, trees should receive increasing amounts of nitrogen per tree up to about five ounces (150 gm) of elemental nitrogen per tree at three or four years of age of the graft. Beyond that age the root system is sufficiently expanded to make broadcast application of nitrogen over the entire orchard more feasible. This also stimulates the sod cover which is necessary to reduce traffic damage to the soil. In fact, broadcast application of fertilizer may be started at grafting if the sod is not thrifty at that time.

During vegetative growth, after broadcast application of nitrogen has been started, amounts of elemental nitrogen up to 100 lbs. per acre (about 100 kgN/ha) per year are needed. Once reproductive growth has started, the amount of nitro-

gen applied can be increased considerably and still result in increased seed yield. The upper limit of nitrogen application has not yet been determined but rates of up to 400 lbs. of elemental nitrogen per acre (about 400 kgN/ha) per year have been tested.

IRRIGATION

Irrigation of seed orchards has been studied far less than their fertilization. However, it has been found beneficial in nearly every test. Irrigation improves grafting success, sod establishment, early vegetative growth, and flowering and seed production. Whereas fertilization primarily tends to stimulate female flower production, irrigation has increased pollen production in Southern pine seed orchards. The need for, and response to, irrigation is highly dependent upon the amount and distribution of rainfall.

Both the need for irrigation and the amount of irrigation needed can be determined through the use of soil tensiometers installed in the seed orchard soil at depths of 12 and 24 inches, (30 and 60 cm). Irrigation is utilized to keep the soil moisture stress between 0.5 and 0.1 atmospheres of tension.

Irrigation in the first year of the reproductive cycle results in more male and female flowers in the second year. Irrigation in the second year reduces conelet abortion and in the third year it results in somewhat longer cones and heavier seeds.

A long-running study of fertilization and irrigation, conducted by the Catawba Timber Co. in Catawba, South Carolina, will be used to illustrate the value of both practices (Table 1). The treatments have been imposed since the orchard was grafted in 1964. Irrigation has been supplied as indicated above and fertilization has included 350 lbs./acre (about 350 kg/ha) of NH_4NO_3 applied in the spring and again in July and 500 lbs./acre (about 500 kg/ha) of 10-10-10 fertilizer in November of each year. This total application of 300 lbs.N/acre (about 300 kgN/ha/yr) was originally intended to be excessive but to date has not been detrimental although it may not represent the optimum rate of application.

Table 1.--Yield of cones per tree in a loblolly pine seed orchard [a/] as affected by irrigation and fertilization

Year	Treatment				
	Control	Irrigation (I)	Fertilization (F)	F + I	$\bar{x}$
	- - - - - - - - - - - - - - - - - - cones/tree - - - - - - - - - - - - - - - - - -				
1971	45	81	60	102	72
1972	72	99	134	145	112
1973	70	88	88	100	86
1974	55	98	117	144	104
$\bar{x}$	61	92	100	123	
Difference		(I-C) 31	(F-C) 39	[(F+I)-C] 62	

[a/] Catawba Timber Co., Catawba, S. C. Tests initiated in 1964.

The effects of both irrigation and fertilization can be seen to be positive in each of the four years although their magnitude changes from year to year. It is instructive to note that where the treatments are applied individually the response totals 70 cones. That is, the response was 31 cones for irrigation and 39 for fertilization. When both treatments were applied to the same trees, the combined response was 62 cones. Thus it may be concluded that the effects of fertilization and irrigation are additive at best. Definitely, their combined effect is not synergistic.

A conservative economic assessment of these data by H. D. Smith (personal communication) using 1974 cost figures indicates a benefit/cost ratio for value of additional seed obtained versus cost of treatments imposed of approximately 27 to 1. That is favorable even if you choose to discount Dr. Smith's assessment by a whole order of magnitude.

It is now generally accepted that irrigation as well as fertilization can have both biologically and economically positive effects on flowering and seed production. Much remains to be determined, however, on the effects of minor moisture stress at critical stages of the reproductive cycle. It is quite obvious from the data at hand that severe moisture stress is not profitable but it has been suggested by several workers (e.g. Shoulders 1967) that minor stress in late summer may trigger flower bud differentiation. Verification and quantification of this phenomenon (if real) should be undertaken soon. Finally, there are interactions that need to be studied among nutrition, moisture stress, and applied active compounds such as the gibberellins. The whole area of chemical regulation of flowering, seed formation, and cone abscission remain to be studied.

SUBSOILING

The practice of subsoiling in seed orchards was born out of desperation. In the early 60's trees in certain orchards were losing apical dominance, patches of cambium on the bole were dying, and roots were appearing on the soil surface. At first it was suggested that fertilization was to blame. When fertilization was stopped the situation got worse. Finally, it was noted that soil compaction was becoming severe and deep subsoiling was attempted (in 1964) in order to "loosen up the soil." Dire consequences were predicted because of all the root cutting involved. The response, however, was favorable and dramatic both above and below ground. Thus, the practice of subsoiling on an operational basis was started. It has continued to the present purely on the basis of visual results.

In 1973, research was finally started in two seed orchards to determine whether it was possible to improve the effectiveness of the subsoiling process. Variables under investigation include shallow (approximately 6 inches or 15 cm) and deep (approximately 18 inches or 45 cm) soil disturbance, early (June) and late (August) summer subsoiling, number of sides of the tree subsoiled (1 or 2) simultaneously, and frequency of repeated subsoiling (every 2 to 5 years).

To date, the 1974 and 1975 female flower counts appear to indicate that subsoiling is of immediate value in stimulating flowering but that we must delay judgment on the relative value of the two depths employed (table 2). Also, late appears better than early subsoiling, although this effect may not persist beyond the first year. No conclusions can be drawn on the other variables under study at this time.

Table 2.--Effect of subsoiling in two seed orchards [a/] on female flower production for two years following treatment

Subsoil treatment	Subsoiled June 1973 Females/tree		Subsoiled August 1973 Females/tree	
	1974	1975	1974	1975
Control	13.4	19.7	14.4	43.8
Shallow	11.9	24.0	23.8	50.2
Deep	11.1	23.5	30.0	48.3

a/Orchards of the Virginia Division of Forestry, Buckingham, VA (June subsoiling) and Union Camp Corp., Murfreesboro, NC (August subsoiling). The data include 6 clones in each orchard.

Root excavations have revealed rapid proliferation of new roots near the cut ends of severed roots. The new roots are abundant, soon bridge the subsoil slit and proliferate beyond it, and in the case of the deep subsoiling, grow down the slit and proliferate in the deeper soil layers. The apparent effect of this new rooting habit is to give the tree improved stability and moisture supply from the action of the new deep roots. Nearly all of the new roots are mycorrhizal. Obviously, more time will have to elapse before these tests can be fully evaluated but these first results appear encouraging. Operational subsoiling will continue as before.

SITE SELECTION AND PREPARATION

Perhaps as much gain in seed yield can be realized by careful selection of new seed orchard sites and their proper preparation as through any of the above discussed techniques. At the moment a large study is underway to delineate critical factors of soil and climate in selecting optimum sites. Thus, we may expect some refinements in our present thinking. However, at this time we do suggest that soils which range from fine sandy loams, through silt loams, to some clay loams (those with good structure and internal drainage) will offer the best opportunities for high seed yield. Primarily these soils have better nutrient- and water-holding properties than the sandier soils and fewer trafficability, compaction, aeration, and drainage problems than the heavier soils. Also the site should not be eroded and a topsoil of at least 8 inches (20 cm) is preferred.

The newest piece of equipment in the arsenal of the loblolly pine seed orchard manager will soon be the vacuum seed harvester. A smooth soil surface will increase seed yield when this machine is used. The best time to prepare for this is during seed orchard site preparation. It is now possible, through

the use of a computer program, to solve the earth moving required to provide the surface shape desired while maintaining a stated minimum topsoil thickness. If significant earth movement is required it will be necessary to subsoil the site before the root stock is planted.

Careful site selection and preparation offer long-term benefits in increased potential for high seed yields. Also they have the advantage of being non-recurring expenses in the life of the orchard. Further refinements in our knowledge in these areas will pay large dividends both in ease of seed orchard management and in seed yield obtained.

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SEED ORCHARD SURVEY (SOS): FINAL REPORT AND SUMMARY OF HIGHLIGHTS

Earl W. Belcher and Gary L. DeBarr[1/]

Abstract.--Analysis of three years of field and laboratory data on cones and seeds of 219 slash and 297 loblolly clones from 29 slash and 26 loblolly seed orchards in 10 southern states have been completed.

Cone production averaged 170 cones per tree at 11 years of age for loblolly and 156 cones per tree at 13 years of age for slash pine. Of the cones produced, 11% of the loblolly and 12.8% of the slash had visible damage by insects. A radiographic evaluation showed 9.9% of the loblolly and 15.0% of the slash pine seed were damaged by insects and 18.0% of the loblolly and 14.7% of the slash pine seed were empty.

The efficiency of these trees to produce viable seed was 32.8% for the loblolly and 23.8% for the slash pine. These figures are very conservative because they do not include preharvest cone and conelet losses.

INTRODUCTION

The Seed Orchard Survey was begun in 1971 as a cooperative project between interested orchard owners and the U.S. Forest Service. It was derived from a proposal by the Southern Forest Tree Improvement Committee[2/] to identify problems, to indicate research needs and to indicate immediate applicable orchard management procedures to improve seed quality and yield.

Establishment of clones in an orchard design creates a specialized environment somewhat different from which the ortets originated. The variation present over a wide range of seed orchard environments was largely spectulative before the southwide seed orchard survey. With the survey now complete, an analysis of the data offers some insights into influences on seed orchard yields.

ANALYSIS PROCEDURE

Only data of clones submitted all three years in the survey (1971-1973) were subjected to a computer analysis. The analysis included 219 slash and 297 loblolly clones from 29 slash and 26 loblolly seed orchards in 10 southern states. A total of 1244 slash and 1649 loblolly pine tree collections were included in the analysis.

1/ Director, Eastern Tree Seed Laboratory, Macon, Georgia and Research Entomologist, SEFES, U.S.F.S., Athens, Georgia respectively. The Eastern Tree Seed Laboratory is operated in cooperation with the Georgia Forestry Commission, Georgia Forest Research Council, Southern Forest Experiment Station, U.S.F.S. and SA, S&PF, U.S.F.S.

2/ ad hoc subcommittee on seed quality and yield: R.G. Hitt (chairman), LeRoy Jones, Carlyle Franklin, John Kraus, and Ron Schmidtling, U.S.F.S.; Ray Goddard, Univ. of Florida, J.B. Jett, N.C. State Univ., and Claude O'Gwyn, International Paper Company.

Input from field and laboratory data included tree age, total cones harvested per tree, number of visible insect damaged cones per tree, estimated cones per bushel, number of cones in a 10 cone sample that opened or only half opened, total number of seed per 10 cone sample, radiographic analysis of the seed, germination data and information as to whether insect control measures had been applied.[1/] Seed per cone, viable seed yield per tree, potential seed yield per tree and the efficiency of each tree were calculated.

A large amount of information was generated by the SOS survey. This paper highlights data by species (Table 1) and by states (Table 3) for all measured and computed variables (Table 2). The data is summarized and discussed for (1) field observations, (2) laboratory findings and (3) production potentials.

DISCUSSION OF FINDINGS

Field Observations

Loblolly pine ranged from 5 to 918 cones per tree with a mean of 170 cones at an average age of 11 years (Table 2). Slash pine produced an average of 156 cones per tree at an average age of 13 years with a low of 14 and a high of 1011 cones per tree. Cone yield varied more between years than within years but relative to other trees a high cone producer remained a high cone producer and a low cone producer remained a low cone producer. Although this survey covers only three years of production from young orchards, this data indicates that more consideration may need to be given to clonal fecundity if the future demands for seed are to be met.

After collection, cones were visually inspected for insect damage. Over the three year period, 11.0% of the loblolly and 12.8% of the slash pine cones were reported as attacked by insects (Table 1). Averages for individual clones ranged from 0 to 67% for loblolly and from 0 to 57% for slash pine clones.

No provisions were made in SOS to identify specific insect pests; however, it is likely that most of the cones were infested by coneworms, Dioryctria spp. Seed yields from Dioryctria infested cones are almost nil (Sartor and Neel 1971) so cones reported as infested in SOS may be considered a total loss. Preharvest losses caused by insects occur over a two-year period for each cone crop and harvest counts of cone crops could underestimate the impact of insects by 50% or more (DeBarr 1974, DeBarr and Barber 1975). Therefore, the SOS estimates of cones lost to insects should be viewed as conservative.

Cooperators were also asked to indicate if the SOS ramets had been protected with insecticides. Over the three-year sampling period, more than 80% of the loblolly pine clones and 60% of the slash pine clones reportedly received at least one insecticide application per year. It appears, however, that, on the average, these treatments had little or no effect upon the percentage of insect-damaged cones occurring over the three-year period for

1/ Specific details on data measurements were previously reported by Belcher and Hitt, 1973.

either pine species. A wide diversity of insecticidal control measures were reportedly used, some of which offered little promise for Dioryctria control.

Cones with no visible insect damage were used to estimate the number of cones per bushel. This data was subject to considerable error since containers were not standardized between orchards and estimates were made to the nearest 1/4 bushel. Regional variations were noted (Table 3) but the low precision of the measurements limit the reliability of the data.

Laboratory Findings

For the three-year period of the SOS, an average of 8 slash pine and 8.6 loblolly pine cones per 10-cone sample opened, yielding 68 and 77 seed per cone respectively (Table 1). A radiographic analysis of the seed showed that 18.0% of the loblolly and 14.7% of the slash pine seed were empty. The cause of the empty seed was not determined.

Based on reported methods (DeBarr, 1970), identifiable seed insect damage was also noted. Radiographs revealed that 9.9% of the loblolly pine and 15.0% of the slash pine seed harvested had been destroyed by insects. The individual clone averages ranged from 0.3 to 37% for loblolly pine and from 0 to 61.3% for slash pine.

These estimates of seed losses caused by seedbugs are very conservative. Research studies have shown that radiographic examination of mature seed samples detects only late second-year damage (DeBarr and Ebel 1973, 1974). Conelet as well as first- and second-year ovule abortion were not identified by SOS, but were reflected only by decreased yields. In addition, some of the empty seed previously mentioned had probably also been destroyed by seedbugs.

The loblolly and slash pine clones which reportedly had been protected with insecticides yielded more seed per cone (Table 4) and had lower percentages of seedbug-damaged and empty seed than the unprotected cones.

Viability as measured by germination is an important aspect of production. The actual (or overall) germination was very low for both species. Loblolly averaged 68.9% and slash 62.5% with a range of 19.7% to 93.2% for loblolly and 22.6% to 90.2% for slash pine seed. However, empty seeds possess no capacity to germinate and thereby distort the true picture of viability. When germination is based on only the filled seed, loblolly averaged 91.6% and slash 81.7%. The filled seed which did not germinate might be attributed to abnormal development and seedbug damage which amounted to 10.4% for loblolly and 16.5% for slash.

The amount of fungal growth in the germination dishes were observed to be in proportion to the amount of seedbug damage and as a general observation almost any amount of seedbug damage is detrimental to seed viability (Rowan and DeBarr, 1974).

Production Potentials

The actual viable seed yield per tree for this survey was 10.0 M for loblolly and 8.0 M for slash as computed by the formula: Yield per tree = (seed/cone)(number sound cones/tree)(actual germination). Averages for individual clones ranged from 0.2 to 70.8 for loblolly and 0.2 to 61.1 for slash pine.

The number of ovules which are potentially capable of producing seed has been reported (Bramlett, 1974) as 170 for slash pine and 155 for loblolly pine. The potential seed yield per tree was obtained from the product of the appropriate seed potential and the total number of cones harvested per tree. The potential viable seed yield was 26.4 M for loblolly and 26.5 M for slash pine.

The efficiency of these trees to produce viable seed was expressed as the ratio of the actual yield to that of the potential yield. This was 32.8% for loblolly and 23.8% for slash pine. Although these figures may seem low they do not tell the whole story. Production efficiency, as defined in this paper, was based on the harvested cone crop and did not account for preharvest cone and conelet losses.

By far, the greatest cause of seed loss identified by the SOS survey was insects. When the data was summarized and analyzed by insect control treatments vs no control, the protected clones averaged about 20% higher in production efficiencies for both species. With the registration and use of more effective insecticides it is reasonable to expect an improvement in present seed production efficiencies.

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Table 1.--Three-year species means and statistics of the measured and computed SOS variables.

Variable[1/]	Loblolly Pine			Slash Pine		
	N	MEAN	C.V.%	N	MEAN	C.V.%
AGE	1610	10.9	23.6	1245	13.1	16.1
CONE-YLD	1528	170.1	137.7	1241	155.8	102.6
PER-INF	1505	11.0	125.9	1238	12.8	121.3
CONES-BU	1114	261.1	38.8	1033	166.1	34.3
SEED-CON	1624	77.1	44.2	1185	68.1	50.6
PER-BUG	1506	9.9	107.1	1058	15.0	91.8
PER-MAL	1506	0.5	537.6	1058	1.5	268.8
PER-EMPT	1506	18.0	81.2	1058	14.7	84.2
PER-SD	1506	71.6	28.4	1058	68.7	29.4
ACT-GER	1595	68.9	29.2	1139	62.5	32.6
FULL-GER	1600	91.6	13.0	1142	81.7	18.7
YLD-TREE	1451	10.0	172.6	1132	8.0	149.5
POT-YLD	1528	26.4	137.7	1241	26.5	102.6
PROD-EFF	1451	32.8	58.4	1132	23.8	68.0

[1/] Defined in Table 2.

Table 2.--Definition of variables used in reporting of the Seed Orchard Survey.

AGE	Average age of trees during the 3-year study duration.
CONE-YLD	Total cones harvested per tree.
PER-INF	Percent of total cones which were insect (Dioryctria) damaged as determined by visual inspection.
CONES-BU	Cones per bushel estimated to nearest 1/4 bushel.
SEED-CON	Mean number of seed extracted per cone.
PER-BUG	Percent age of seed sample damaged by seedbugs as evaluated on radiographs.
PER-MAL	Percent age of seed sample which appeared abnormally developed or malformed on radiographs.
PER-EMPT	Percent age of seed sample which appeared empty on radiograph and could not be attributed to seedbug damage.
PER-SD	Percent age of seed sample which appeared full and nondamaged on radiograph.
ACT-GERM	Actual germination. Germination of lot as it is.
FULL-GERM	Full seed germination. Germination of only filled seeds.
YLD-TREE	Viable seed harvested per tree (in thousands).
POT-YLD	Potential yield of viable seed per tree (in thousands) based on published mean seed potential per cone and number of cones harvested.
PROD-EFF	Ratio of actual to potential seed yield per tree.
N	Number of ramets involved in determination of mean.
C.V.%	Coefficient of variation.

Table 3.--Three year means of measured and computed SOS variables by state in which orchards are located.

STATE	N	AGE	CONE-YLD	PER-INF	CONES-	SEED-CON	PER-BUG	PER-MAL	PER-EMPT	PER-SD	ACT-GERM	FULL-GERM
						Loblolly Pine						
AL	76	9.4	104.3	9.0	195.7	60.5	3.2	0.9	19.6	76.3	73.8	93.8
FL	15	12.6	666.4	3.6	298.3	100.3	9.2	0.4	18.6	71.8	67.6	92.1
GA	154	9.1	196.5	17.8	329.9	51.4	13.6	2.6	24.8	59.0	58.8	91.0
LA	156	11.1	113.5	10.9	265.9	79.4	9.7	0.4	14.4	75.4	70.5	90.1
MI	150	11.4	113.1	11.8	246.6	86.7	6.7	0.2	12.3	80.8	78.3	94.4
NC	419	12.4	166.3	11.4	242.2	92.1	7.5	0.3	14.3	77.9	75.1	93.6
SC	517	10.3	188.4	8.7	258.8	74.6	11.9	0.2	19.6	68.2	66.3	90.8
TE	42					50.2	8.9	0.6	24.8	65.7	65.2	93.2
TX	50	14.9	296.1	14.3	353.2	48.6	21.8	0.0	43.7	34.5	36.1	84.0
VA	57	10.6	15.9	29.1		80.5	10.8	2.1	14.7	72.5	65.0	85.0
						Slash Pine						
AL	56	13.3	112.6	12.0	151.5	79.0	17.9	0.2	10.5	71.4	59.1	69.0
FL	500	13.5	154.8	11.9	177.0	68.4	17.1	1.8	13.3	67.7	61.5	81.5
GA	435	13.2	146.6	13.6	152.8	64.8	13.2	1.5	13.5	71.9	65.0	82.9
LA	54	9.7	155.0	3.9	180.7	61.1	10.8	1.0	30.9	57.3	51.6	78.6
MI	59	13.7	171.7	33.7	156.5	83.4	10.4	2.8	8.5	78.3	70.3	82.8
NC	60	12.8	155.9	14.1	165.9	80.7	9.5	0.4	17.6	72.5	70.3	91.4
SC	44	12.6	277.9	3.0	202.0	66.0	17.5	0.7	24.8	57.1	57.1	83.8
TX	37	12.7	173.8	5.3	152.8	52.5	22.9	1.1	21.5	54.5	51.6	75.1

Table 4.--Comparison of data from clones protected with insecticides and unprotected clones--SOS 1971-1973.

Insecticide protection	Number of clones	% Insect-damaged cones	% Seedbug-damaged seed	% Empty seed	Number of seed/cone
			LOBLOLLY PINE		
Yes[1/]	247	11.2	8.8	16.9	78.2
No	30	10.0	14.0	25.4	69.3
Unknown[2/]	21	10.1	15.4	18.8	75.5
			SLASH PINE		
Yes[1/]	128	11.2	14.1	13.4	73.7
No	75	14.8	16.4	16.5	60.1
Unknown[2/]	16	14.6	16.7	18.4	62.7

1/ Insecticide applied at least once each year.

2/ Not reported by Cooperator; may or may not have been protected.

FERTILIZER TIMING AND FORMULATION AFFECT FLOWERING IN A LOBLOLLY PINE SEED ORCHARD

R. C. Schmidtling[1/]

Abstract.--Fertilizer trials in a Mississippi seed orchard showed that N stimulated flowering, P did not, and N + P was no better than N alone. Of three nitrogen sources tested, NH_4NO_3 proved most effective in one experiment; but response to NH_4NO_3 and to $NaNO_3$ was about the same in another experiment. Fertilizing in mid to late summer produced the greatest increase in flowering (as much as 300 percent); the best treatment (fertilized July 26) tripled cone yield and quadrupled yield of sound seed. Fertilized ramets were no taller than controls, but diameter growth was improved by treatments. Clone x treatment interactions were always significant.

Additional keywords: Pinus taeda, nitrogen source, seed production.

Soil fertility, one of the chief environmental factors affecting fruitfulness in conifers, is usually controlled with fertilizers. The effectiveness of the treatment depends on the formulation, rate, application method, timing, and their interactions with soil type and water relations. This paper reports the effects of different times of application and different fertilizer formulations on loblolly pine (Pinus taeda L.).

MATERIALS AND METHODS

In 1970 a series of six fertilizer experiments was initiated in the U. S. Forest Service's Erambert Seed Orchard near Brooklyn, Mississippi. Three experiments tested time of fertilizer application; two evaluated responses to different nitrogen sources; and one was an N-P factorial, testing effects of nitrogen, phosphorous, and the N-P combination.

The orchard is composed of loblolly ramets from south Mississippi that had been grafted to nursery-run seedling rootstocks of local source. Nearly all the ramets used in these experiments are on three soil types: Ruston, Norfolk, and Luka loamy sands. N and P in soil analyses averaged 280 p/m and 5.7 p/m at a 6- to 8-inch depth.

Many aspects of experiment design were the same for all six experiments (table 1). Randomized complete blocks with single-tree plots were used throughout. All experiments were designed so that clonal and clone x treatment effects could be evaluated. No ramet was used in more than one experiment, nor was any ramet treated more than once in any experiment. Different clones were used for each experiment with the exception of

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Table 1.--Details of six fertilizer experiments

Experiment	Time of establishment		Clones	Blocks	Treatments	Fertilizer N	Fertilizer P_2O_5	Fertilizer K_2O	Graft age	Trees in study
	Year	Month	----------No.----------			Gms./tree			Yrs.	No.
Timing I	1970	*	7	7	7	57	11	11	5	343
Timing II	1971	*	6	6	6	91	18	18	5	216
Timing III	1972	*	6	5	4	272	--	--	6	120
N-P factorial	1972	July	7	8	4	272	272	--	6	224
N-source I	1971	May	3	5	4	113	--	--	6	60
N-source II	1972	July	8	8	3	272	--	--	6	192

*See figure 1.

N-source II, which had some clones in common with the N-P factorial. Fertilizers were applied in four equally spaced holes under the dripline of the crowns and followed by about 1/2 liter of water before the holes were closed.

Strobili were counted for 2 or 3 years before and for 2 years after treatment. Heights were measured before and for 2 years after treatment. Diameter measurements were made before and after treatment in the N-P factorial and timing II experiments, and after treatment in the timing I experiment. In the fall of 1973, cones from all trees in the timing II experiment were harvested. Seed were extracted, counted, and weighed.

All count data were transformed to $\sqrt{\text{count} + 1}$ for analyses of variance. All statistical tests were at the 0.05 level of probability. Treatments are assumed to be fixed effects, clones random.

RESULTS AND DISCUSSION

Flowering in the seed orchard varied considerably from year to year. Female strobili production was below average in 1970, slightly above average in 1972, and above average in 1973. However, proportional increases in flower production caused by fertilizer treatments were about the same in all three years.

Timing

Fertilization in March increased flowering by 50 percent over controls (fig. 1). Flowering increased with progressively later fertilizer applications until it peaked with the August treatment at about 300 percent over controls. Response dropped sharply after August, but flowering was still about 30 percent over controls in ramets fertilized in the first week of

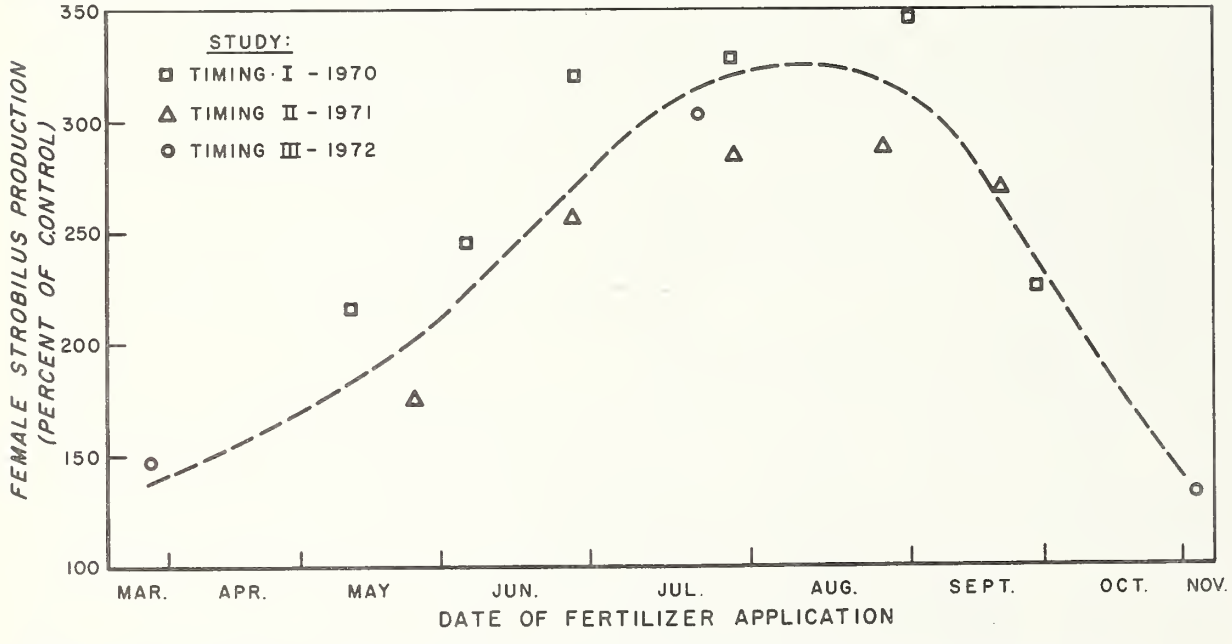

Figure 1.—Female strobili production in young loblolly pine grafts in response to timing of fertilizer application. Dashed line represents the generalized response for the three experiments.

November. Hence, fertilizing rather late in the year is best for inducing flower production in loblolly pines.

These results can be explained on the basis of growth and carbohydrate accumulation in relation to time of flower formation (Schmidtling 1974, Shoulders 1970). Fertilizers should be applied early enough to increase flower initiation (or perhaps prevent abortion of already formed primordia) but late enough to minimize uptake by competitors or diversion of nutrients to growth rather than flowering. Late summer application may also be beneficial to second-year cones since they accumulate most of their nitrogen at this time (Dickmann and Kozlowski 1969).

N-P factorial

The fertilizers (ammonium nitrate and triple super phosphate) were applied in late July, the optimum time as indicated by the timing experiments. Application of nitrogen increased female flowering threefold, P alone had little effect, and N + P was about the same as N alone (fig. 2).

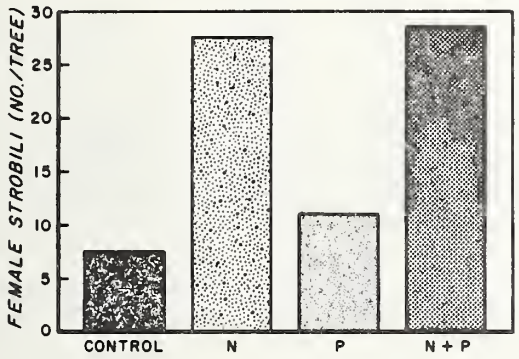

Figure 2.--Flowering of young loblolly pine grafts in an N-P factorial fertilizer experiment.

Nitrogen source

In both experiments, all nitrogen sources enhanced flowering over controls (fig. 3). In N-source I, tree fertilizers, nitrate of soda, ($NaNO_3$), ammonium sulfate ($(NH_4)_2SO_4$), and ammonium nitrate (NH_4NO_3), were applied in May, which is a little earlier than desired in view of results from the timing experiments. Differences between control and the fertilized ramets and differences among fertilizer treatments were all significant. Fertilizing with $NaNO_3$ doubled flowering and fertilizing with $(NH_4)SO_4$ tripled female flowering, but the combined source NH_4NO_3 was best.

In N-source II, $NaNO_3$ and $(NH_4)_2SO_4$ were applied in July, near the optimum time. The difference in timing between the two experiments may have some bearing on the results. As with N-source I, the difference between fertilized ramets and controls was statistically significant (table 2). However, differences between the two fertilizer treatments were not significant; both increased flowering fourfold over controls (fig. 3).

Table 2.--Analysis of variance for experiment N-source II

Effect	D.F.	Mean squares	Expected mean squares
Block (r)	7	6.171 *	$\sigma^2 + ct\,\sigma_r^2$
Clone (c)	6	44.935 *	$\sigma^2 + rt\,\sigma_c^2$
Treatment (t)	2	68.014 *	$\sigma^2 + \frac{t}{t-1} r\,\sigma^2_{ct} + rc\,\frac{\Sigma\,\tau^2}{t-1}$
Control vs. N	1	132.679 *	
within N	1	3.348	
Clone x treatment	12	2.624 *	$\sigma^2 + \frac{t}{t-1} r\,\sigma^2_{ct}$
C X (Control vs. N)	6	4.003 *	
C X (within N)	6	1.246	
Error	140	1.426	σ^2

*Significant at 0.05 level of probability.

$\sigma_r^2 = 0.226 \quad \sigma_c^2 = 1.855 \quad \sigma_{ct}^2 = 0.0916 \quad \Sigma\,\tau^2/t\text{-}1 = 1.166$

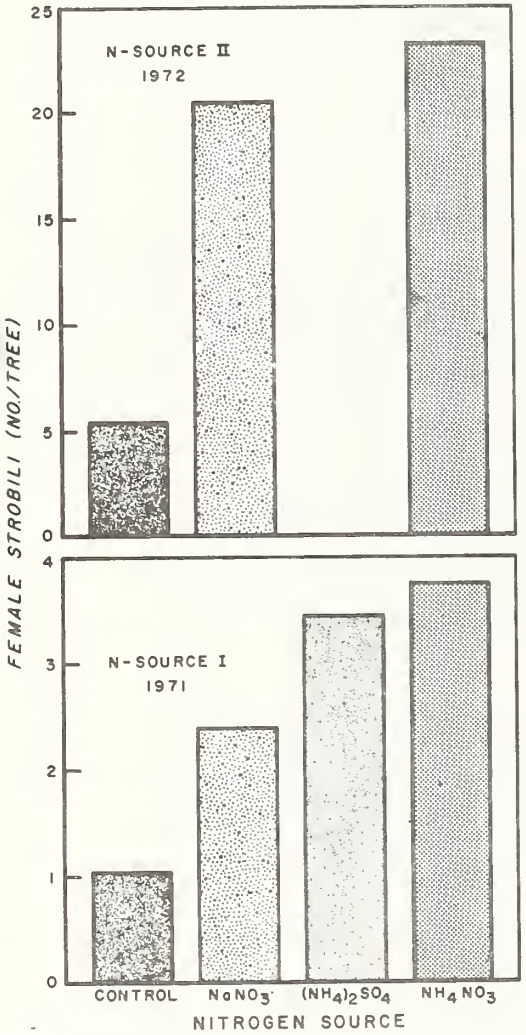

Figure 3.--Flowering response to different nitrogen fertilizers in young loblolly pine grafts.

Although this area of fertilizer research deserves more study, the practical implications are straightforward: ammonium nitrate was as good as or better than any other fertilizer tested. There is no indication in this study of a preference for nitrate source in eliciting flowering response in loblolly pines as has been found in Douglas-fir (Ebell and McMullan 1970).

Residual effects

In every experiment, fertilized trees produced more flowers than controls the second year after treatment. Generally, the differences were not as large as the first year, nor were they statistically significant in all cases, but they were always apparent. However, in the three timing experiments, fall applications had a greater effect on second-year flowering than on the first-year flowering; mid- to late-summer applications were most effective the first year.

Clonal differences

In every experiment, clonal differences were significant and constituted a major component of total variation. For example, in N-source II (table 2 and fig. 4),

treatment effects accounted for 35 percent of the total variation. Clonal effects were much larger, however, accounting for 56 percent of the total variation. These figures are typical for all six experiments.

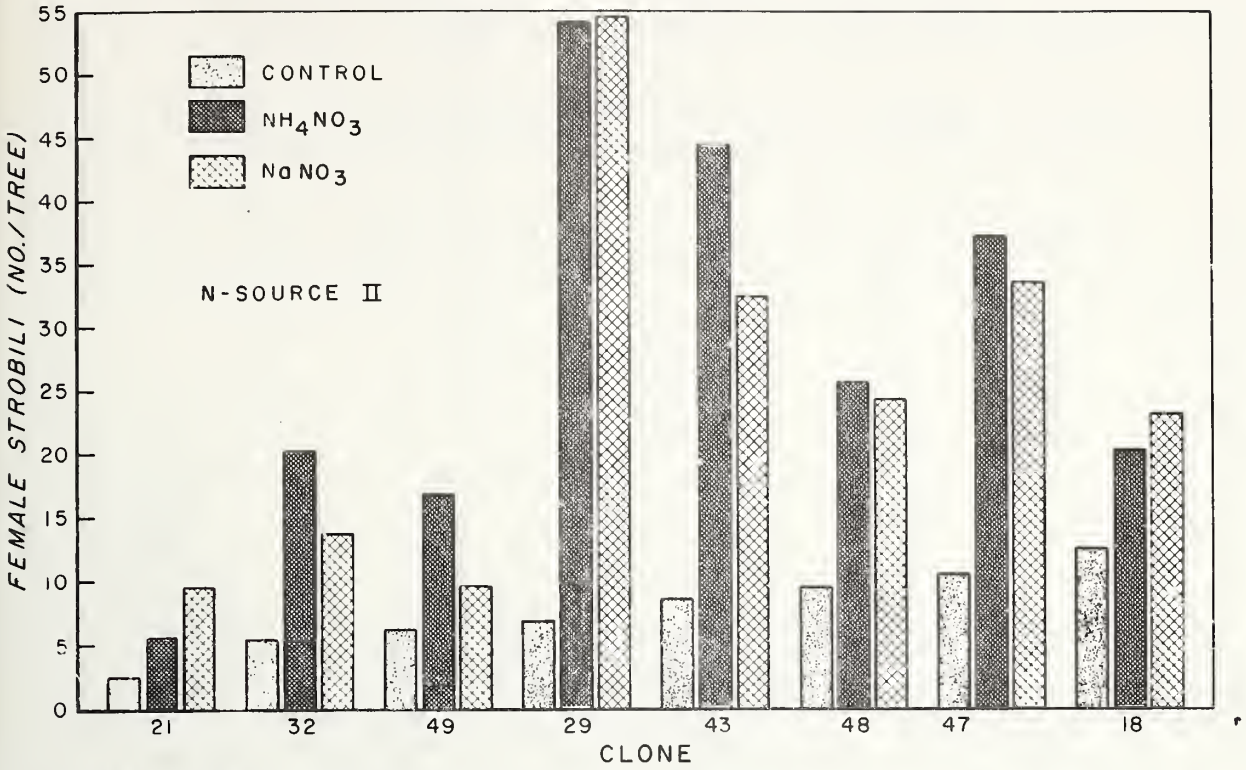

Figure 4.—Flowering response of eight loblolly pine clones to two sources of nitrogen fertilizer (N-source II).

In general, better flowering clones responded best to fertilization. However, there were some exceptions, especially in N-source II. Clone 29 (fig. 4) was less than average in flower production when not fertilized but was by far the best flowering clone when fertilized. In all but one experiment (N-source I), clone x treatment interactions were significant. The interaction in each case was made up primarily of the control vs. fertilized component. For example, clones did not respond differently to the various times of fertilization, but they did respond differently to the application of fertilizer itself. Similarly, in N-source II (table 2 and fig. 4), little of the interaction resulted from a differential clonal response to source of nitrogen.

Cone and seed yield

In the one experiment which included cone collection (timing II), only 21 percent of the female strobili produced harvestable cones. Nevertheless, the number of seed produced was always greater for fertilized trees than for controls (table 3). The July 26 application appeared best in terms of numbers of cones and sound seed produced. The variable nature of cone survival makes conclusions preliminary, but the larger number of flowers resulting from fertilization will most likely also increase seed production.

Table 3.--Cone and seed yields from timing II experiment

Treatment	Female strobili	Harvestable cones	Sound seed total	Sound seed /cone	Weight/ 100 seed
	----------No.----------				Gms.
Control	144	42	675	16	3.15
Fertilized					
May 27	247	72	1701	24	3.22
June 28	409	62	1295	21	2.94
July 26	400	156	2832	18	3.15
Aug. 23	445	48	1028	21	3.34
Sept. 20	364	26	862	33	3.39

Growth

In none of the experiments did treatment significantly affect height growth, though clonal effects were usually significant. Diameter, which was measured in only three experiments, was affected significantly by fertilization in all cases. In the N-P factorial, N stimulated diameter growth, P did not, and N + P was no better than P. Diameter growth in timing I and II was in line with what one would expect: fertilizing early in the year tended to affect growth in the same year fertilizer was applied; fertilizing later in the year affected the next year's growth.

CONCLUSIONS

Results of the six experiments indicate that fertilizers should be applied to loblolly pine seed orchards late in summer. Nitrogen seems to be the important component, though phosphorous may be beneficial on a P-deficient site, which the Erambert Seed Orchard apparently is not. Ammonium nitrate is as good as or better than either an ammonium source or nitrate source alone.

Clonal effects and interactions with clones are important in measuring flowering and should be accounted for in any experimental design.

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POLLINATION IN A SLASH PINE SEED ORCHARD

David L. Bramlett and C. Joy Johnson[1/]

Abstract.--Sample conelets from a slash pine seed orchard were collected 4-7 months after pollination. The conelets were dissected and the ovules on each fertile scale classified as healthy or aborted on the basis of macroscopic appearance. An average of 159 ovules per conelet (96%) were healthy in the 216 conelet sample. Microscopic examination of a subsample of ovules indicated that all ovules classified as healthy had one or more germinating pollen grains present. The high percentage of healthy ovules in the conelet stage indicates that both adequate pollination and excellent insect control were evident in this orchard. High seed yields per cone can be expected at cone maturity if the cones and seeds are adequately protected from insects during the second year of development.

Additional keywords: Pinus elliottii, aborted ovules, insect control

Mortality of ovules before cone maturity can seriously reduce the seed yield in pine seed orchards. For example, mature cones sampled from a Georgia slash pine (Pinus elliottii Engelm) seed orchard in 1972 had a seed efficiency of only 16 percent (Bramlett 1974). Large seed losses were attributed to ovule abortion during the first year of development (110 ovules/cone) and to a lesser degree ovule abortion during the second year (17 ovules/cone). Thus the 1972 study identified first year ovule abortion as a major factor in the poor seed yield of this slash pine seed orchard.

Two separate causes of first-year abortion in pine ovules are known. McWilliam (1959) and Sarvas (1962) have reported that unpollinated ovules abort during the first growing season. In addition, DeBarr and Ebel (1973) reported first year aborted ovules in southern pines from feeding damage of seed insects.

Therefore, studies to evaluate first-year ovule abortion in southern pines must take into account both insect damage and the adequacy of pollen. In the study reported here, insect attack was minimized by spraying the orchard trees, and pollination of ovules was observed microscopically. In another paper at this Conference, DeBarr et al. (1975) estimate the impact of seed insects from the seed yields of screened and unscreened cones.

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METHODS AND MATERIALS

Six conelets on each of 3 ramets from 4 slash pine clones were collected on June 4, July 24 and September 18, 1974 from the Arrowhead Seed Orchard Pulaski County, Georgia. The seed orchard was sprayed for insect control with 1% Guthion(R)[1/] at 3-4 week intervals from April-September 1974. All the scales on each conelet were removed and the ovules on the fertile scales classified as aborted or healthy on the basis of macroscopic appearance. Sample scales and ovules for microscopic examination were fixed in FAA. Following dehydration with tertiary butyl alcohol the ovules and scales were embedded in Tissuemat (mp 55-56°C.). Serial sections were cut at 12 to 20μ on a rotary microtome and stained with Safranin 0 and Aniline Blue.

RESULTS

Conelet Development

The conelets had attained full size by June 4 and showed no increase in size or change in seed potential by the September 18 collection (table 1). Differences between clones and between ramets nested in clones were evident for both conelet size and seed potential (table 2).

Table 1.--Conelet length and seed potential for slash pine conelets collected June, July and September

Clone	Conelet length			Seed potential		
	June 4	July 24	Sept 18	June 4	July 24	Sept 18
	- - - - - Inches - - - - -			- - - - - Number - - - - -		
30	.88	.88	.88	169	171	172
56	1.08	1.06	1.05	164	170	159
92	1.08	1.06	1.06	171	172	172
134	1.11	1.13	1.13	162	157	151
Average	1.04	1.03	1.03	167	167	163

Ovule Development

Healthy ovules.--Ovules classified as healthy from macroscopic appearance greatly outnumbered aborted ovules in the dissected conelets (table 3). Averages for the three collection dates ranged from 156 to 160 and showed no statistical differences (table 2). The high number of healthy ovules also represented a high percentage of the seed potential (table 1) and averaged 96% for the dates observed.

1/ Guthion is registered for cone and seed insect control in southern pine seed orchards.

Table 2.--Results from analyses of variance for variables from 216 slash pine conelets

Source of variance	Mean squares for variable[1/]			
	Length	Seed potential	Aborted ovules	Healthy ovules
Clones	5835.9**	2652.9*	2222.9**	9361.5**
Ramets in clones	180.8**	518.1**	180.8	853.7**
Collection dates	5.3	320.7	10.5	443.4

[1/] Averages significantly different at the $0.01^{(**)}$ and $0.05^{(*)}$ level of probability.

Table 3.--The number of healthy and aborted ovules in June, July and September collections of slash pine conelets

Clone	Healthy ovules			Aborted ovules		
	June 4	July 24	Sept 18	June 4	July 24	Sept 18
	- - - - - - - - - - - - Number - - - - - - - - - - - -					
30	167.0	163.9	170.9	2.4	6.7	.9
56	163.3	166.4	150.2	.9	3.2	8.9
92	170.7	170.2	165.8	.4	2.2	5.9
134	139.4	143.1	138.2	22.1	13.9	12.8
Average	160.1	160.9	156.3	6.5	6.5	7.1

Microscopic examination indicated that all sample ovules classified as healthy contained one or more pollen grains. Furthermore, all healthy ovules showed pollen germination and pollen tube growth that had penetrated about one-half of the nucellar tissue. Morphological development during the summer was similar to that described by Ferguson (1904).

Aborted ovules.--Unlike in 1972 cones, very few ovules were aborted in the 1974 conelets. The observed aborting ovules appeared discolored, with necrotic or resinous areas near the center of the ovule. The number of aborted ovules for each collection date was very similar averaging from 6.5 to 7.1, per conelet (table 3). The number of aborting ovules per conelet ranged from 0 to 77. Clonal and ramet differences were evident for aborted ovules per conelet but differences due to ramets or collection dates were not significant (table 2).

Prepared slides of aborting ovules indicated complete breakdown of the interior of the ovule. The integument was usually collapsed and large portions of the ovule were completely missing. In several ovules a portion of the nucellus with pollen grains remained although the rest of the ovule was completely missing. This type of damage was reported by DeBarr and Kormanik (1975) in which the missing portion of the ovule was caused by digestive action of enzymes of the feeding insects.

A few aborted ovules were observed that were not necrotic or resinous but lacked the color of healthy ovules and were typically smaller than normal ovules. Sections of these ovules showed that they had poor development of the female gametophyte. In addition, no pollen grains or pollen tube development were noted. Further observations are needed to accurately correlate this type of macroscopic ovule classification with microscopic evaluation.

CONCLUSIONS

The high percentage of healthy ovules in sample conelets from the Arrowhead Slash Pine Seed Orchard is encouraging. These healthy ovules consistently showed evidence of abundant and viable pollen. Thus, if the seed crop can be protected from insects until cone maturity, a high seed efficiency is expected.

It appears that the rigorous spray schedule in the orchard is the major factor responsible for the low numbers of aborting ovules.

The procedures used here to evaluate first year ovule abortion may be useful to the orchard manager. Routine sampling and macroscopic examination of conelets from the orchard can be used to quantify the first-year ovule loss. If this mortality is high, inadequate insect control should be suspected and the current spray program evaluated. Screen cages or microscopic tests can confirm the separation of insect from non-insect related mortality.

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VARIATION IN SYCAMORE SEED QUALITY

J.A. Mullins, Jr. and S.B. Land, Jr.[1/]

Abstract.--Type-M, "wet film" X-ray method provides better resolution of embryos in sycamore achenes than does "instant paper" X-ray process. "Wet film" radiographs allow designation of four embryo classes: full, partial, abnormal, and empty. Achene weight, percent germination, and rate of germination differ significantly between empties, abnormals, and the combined class of partials and fulls, but not between partials and fulls. Seven-day hypocotyl length does not vary significantly among embryo classes, but does among full achenes of different mother-tree seed lots. Significant phenotypic variation among families for achene weights, percent germination, and germination rate is also present.

Forest tree seed orchard managers must be concerned not only with seed yields, but also with seed quality. Quality here refers to the performance potential of the seed. Performance potential of every non-germinable seed is zero, but that of every germinable seed is not 100 percent (Delouche and Baskin, 1970). Seed vigor, as used in agricultural crop seed technology, is the measure of environmentally-caused differences in performance potential among seed lots of the same genetic variety. In this paper seed quality is used as an encompassing category of many measures of performance potential that are influenced by both environmental and genetic factors.

The achene, or true fruit of American sycamore (Platanus occidentalis L.), is often called the seed. But the seed is actually enclosed within the achene wall. The only non-destructive method of examining the seed embryo is by soft-tissue X-ray radiographs. Can such radiographs provide sufficient resolution to detect embryo differences, other than full and empty achenes, in sycamore seed lots? Furthermore, if such differences can be detected, do they reflect differences in performance potential, and what are measures of performance potential? Finally, is there significant phenotypic variation among sycamore seed lots in these measures of performance potential? Answers to these questions are being sought, and initial results of an ongoing study are provided in the present paper.

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MATERIALS AND METHODS

Sixteen open-pollinated mother tree seed lots were used. Each mother tree represented a different seed source in the Midsouth (Figure 1). There were four seed sources on each of four latitudinal transects.

Soft tissue X-ray radiographs, using the "instant paper" process (Belcher, 1974), were made of the sixteen seed lots, where each seed lot was represented by 1000 randomly-selected seed fixed in position on a self-adhesive paper label. Achenes were separated into classes, based on embryo appearance in the radiographs, by comparing achene positions in the radiographs with positions on the self-adhesive paper. After separation, each class for each mother tree lot was re-X-rayed using the M-type "wet film" process (Belcher, 1968). Numbers of misclassified embryos from the "instant paper" process were recorded and lots reseparated into classes based on "wet film" embryo appearance.

Weights to the nearest 0.1 milligram were taken on four 10-achene samples from each embryo class in each mother tree lot and expressed as grams per 1000 achenes. Two of these samples from each lot were surface sterilized by soaking in a one-percent hypochlorate solution (clorox) for 30 seconds and rinsing three times with distilled water. The two sterilized and two non-sterilized 10-achene samples from each lot were placed on moist blotter paper in a dark germination chamber set for twelve hours at 30° C and twelve hours at 20° C each day. Germination counts were taken at three, five, and seven days following placement of the achenes in the germinator. Hypocotyl lengths were measured to the closest millimeter on each surviving germinant on the seventh day. Germination index, which is a measure of rate of germination and thereby of performance potential, was calculated as follows:

$$\text{Germination Index} = [\%\ \text{germination at day 3}] + [(\%\ \text{germination at day 5})/2] + [(\%\ \text{germination at day 7})/3].$$

Ten seed of each embryo class (except empty seed) in each mother tree lot were planted in each of three replications in a nursery in May, 1975. Percent germination after eleven days in the nursery was measured, and additional measurements of germination and growth will be taken during the summer of 1975.

RESULTS AND DISCUSSION

X-ray Radiographs

The M-type "wet film" process provides additional resolution of sycamore achene embryos not given by the "instant paper" process. Full and empty achenes can be distinguished on "instant paper" radiographs, but there are a number of unclassified achenes having unclear embryo images. M-type, "wet process" film allows the detection of the following four embryo classes:

(a) Full -- Embryo image appears strong and fills the seed cavity.

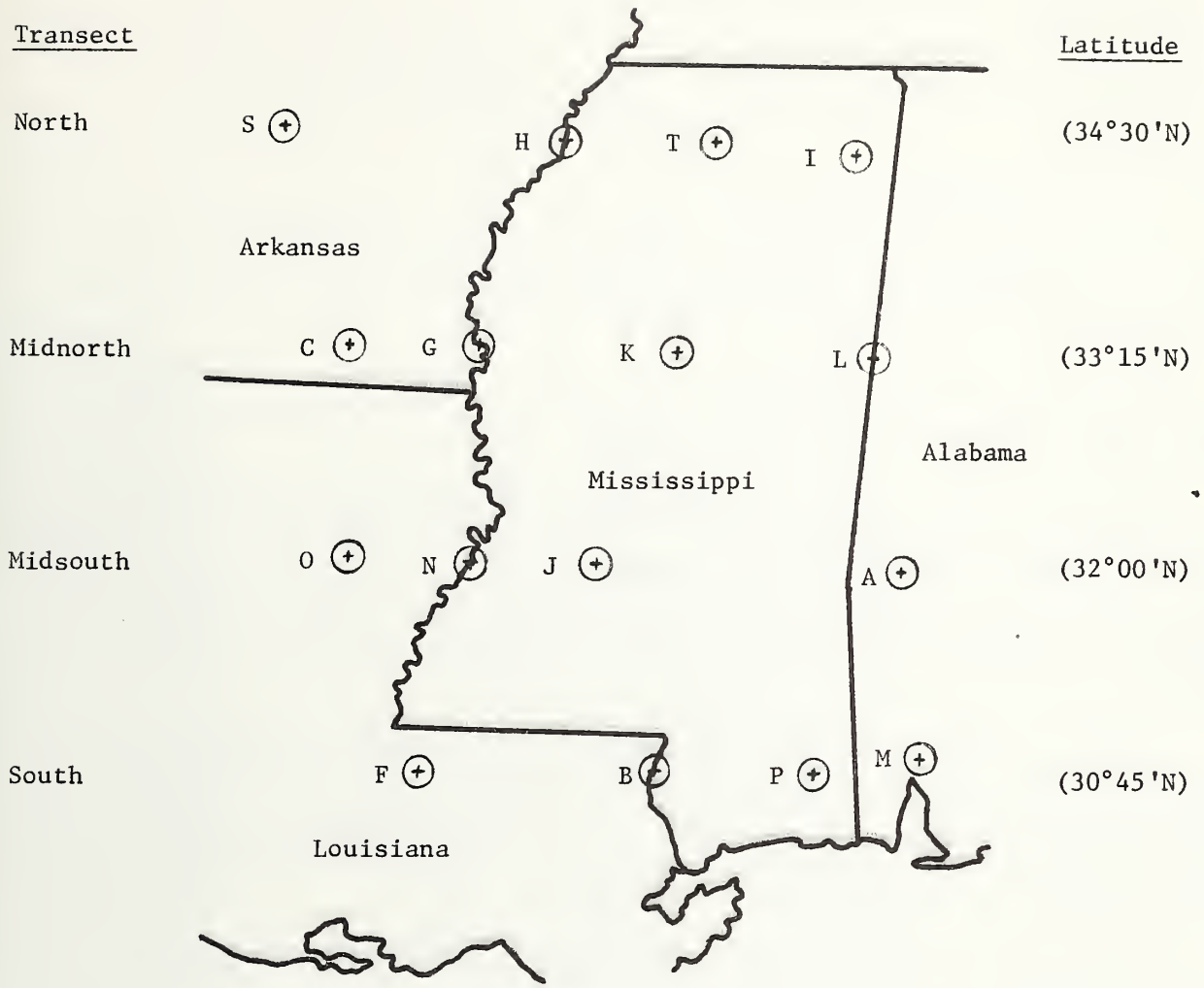

Figure 1.--Locations of mother trees used in study of sycamore seed quality.

(b) Partial -- Embryo image appears strong, but does not completely fill seed cavity.

(c) Abnormal -- Embryo image appears weak, incomplete, or shriveled.

(d) Empty -- No embryo image apparent.

Many of the full achenes from the "instant paper" process are determined to be partials by the "wet film" process, while unclassified achenes are primarily abnormals.

Variation in Seed Quality Among Embryo Classes

Highly significant variation in achene weight, percent germination, and germination index was detected among embryo classes (Table 1). But full and partial classes were never significantly different--the significant variation being among fulls and partials vs. abnormals vs. empties (Table 2).

Full and partial classes were heavier, had a higher percent germination, and germinated faster than abnormals. Abnormals, in turn, were correspondingly greater for these traits than empties.

Germination after eleven days in the nursery was similar to the above results in differences among the four embryo classes (Table 2). Full and partial classes may be combined in interpreting X-ray radiographs of seed lots for nursery production purposes, but abnormals and empties should be considered as non productive. The "instant-paper" X-ray process should be suitable for such interpretations, since the full class from this process contained most of the true full and partial achenes.

Hypocotyl length of surviving germinants after seven days in the germinator is not a suitable measure of differences among classes. What few seed germinated and survived from the empties and abnormals grew as tall as did those from fulls and partials. The hidden difference among embryo classes is in the number that germinated and survived: 409 fulls, 362 partials, 125 abnormals, and seven empties of 640 seed per class.

Surface sterilization of achenes with dilute clorox resulted in both increased percent germination and faster germination. It also reduced the error component of variance (Table 1), thereby increasing precision in detecting differences among classes and among family seed lots. Such sterilization procedures are recommended for studies of phenotypic variation in sycamore seed quality.

Variation in Seed Quality Among Mother-Tree Seed Lots

Variation among mother-tree seed lots in percent germination and germination index was highly significant, but there was no apparent trend among latitudes of the sources (Tables 1 and 3). Interaction of families with embryo classes was also significant, because nearly all mother-tree-family

Table 1.--Analyses of variance for measures of sycamore seed quality from sixteen mother trees in the Midsouth

Source of Variation	d.f.	Achene Wt. M.S.	d.f.	M.S. 7-Day Germination (%) Steril.[a]	Unster.	Germination Index[b] Steril.	Unster.	d.f.	Hypocotyl Length (Ster. Full Embryos) M.S.
Family	15	17.32**	15	1193**	2739**	1435**	1221**	15	15.13**
Embryo Class	3	14.85**	2	29279**	18959**	26966**	4776**		
F x C	45	.25**	30	265**	244	368**	220**		
Error	192	.04	48	103	237	93	101	16	2.88

[a] Sterilized refers to seed that were surface sterilized with clorox.

[b] Germination index is an expression of rate of germination.

Table 2.--Sycamore seed quality means for four seed embryo classes and results of Duncan's New Multiple Range Tests[a/]

Embryo Class	Achene Wt. (gm./1000 achenes)	7-day Germination (%)		Germination Index[b/]		Hypocotyl Length at 7 days (mm.)	Nursery Germin. (%) at 11 days
		Sterilized	Non-sterilized	Sterilized	Non-sterilized		
Full	3.7 a	91 a	74 a	88 a	41 a	12.2	9
Partial	3.4 a	74 a	54 a	69 a	27 ab	12.9	9
Abnormal	3.1 b	33 b	14 b	32 b	13 bc	13.4	3
Empty	2.6 c	2	1	2	1	13.8	-

[a/] For a single seed quality measure, means not followed by the same letter are significantly different at the five percent probability level.

[b/] Germination index is a measure of rate of germination. Higher values reflect faster rates of germination.

Table 3.--Mother-tree family means and results of Duncan's New Multiple Range Tests[a/] for sycamore seed germination and hypocotyl lengths

Mother-tree Seed Lot	7-Day Germination (%) (Surface Sterilized) Full	Partial	Abnormal	Germination Index[b/] (Surface Sterilized) Full	Partial	Abnormal	Hypocotyl Length (mm.) (Sterilized, Full)
South Transect[c/]:							
M	85a	65CD	25defg	80A	60cd	25DE	14.5ab
P	100a	45DE	5g	100A	35ef	5F	10.2c
B	95a	70BC	30cdef	95A	68bc	30DE	14.9ab
F	95a	85ABC	55ab	90A	85ab	55ABC	14.7ab
(Transect Mean)	(94)	(66)	(29)	(91)	(62)	(29)	(13.6)
Midsouth Transect:							
A	95a	80ABC	35bcde	84A	80abc	35CDE	9.2cd
J	90a	65CD	5g	88A	55de	5F	11.2bc
N	95a	95A	65a	95A	95a	65A	11.9cd
O	95a	70BC	35bcde	90A	65bcd	35CDE	9.8cd
(Transect Mean)	(94)	(78)	(35)	(89)	(74)	(35)	(10.5)
Midnorth Transect:							
L	50b	45DE	5g	50B	35ef	5F	11.4bc
K	85a	40E	20efg	83A	25f	15EF	6.2d
G	95a	90AB	50abc	93A	90a	43BCD	12.1bc
C	100a	75ABC	35bcde	98A	55de	30DE	9.9cd
(Transect Mean)	(83)	(63)	(28)	(81)	(51)	(23)	(9.9)
North Transect:							
I	85a	90AB	35bcde	78A	83ab	35CDE	15.2ab
T	100a	90AB	45abcd	100A	90a	45ABCD	16.5a
H	100a	95A	15efg	100A	95a	13EF	14.7ab
S	95a	90AB	60a	93A	90a	60AB	14.6ab
(Transect Mean)	(95)	(91)	(39)	(93)	(90)	(38)	(15.3)

[a/] For a single seed quality measure, means not followed by the same letter are significantly different at the five-percent probability level.
[b/] Germination index is a measure of rate of germination. Higher values reflect faster rates of germination.
[c/] See transects in Figure 1.

variation was for partial and abnormal classes (Table 3). For definitive phenotypic studies of sycamore seed germination, family seed lots should be analyzed for each of the four embryo classes. Otherwise, differences among seed lots may be due to differences in percentages of each embryo type in each lot. "Wet-film" X-ray procedures will therefore be required in such studies of variation.

Germination index was not particularly better than percent germination for detection of family differences in the present study. Ninety-four percent of the germination occurred before the first measurement at three days, creating similar index and percent values. For germination index to be more definitive, measurements should also be taken on the first and second days.

Hypocotyl length of seedlings from the surface-sterilized, full achenes was highly significantly different among families (Table 1). Mean family lengths varied from 6.2 mm. to 16.5 mm. after seven days in the germinator. This measure of seed quality will be important in studies of phenotypic variation. Such studies will not require separation of embryo classes, since germinated seedlings from all four classes performed similarly for a family lot.

Mother-tree family variation in achene weight for each of the four embryo classes was highly significant. Mean full achene weights per 1000 achenes for families varied from 1.98 grams to 6.52 grams (Table 4). Empty achene weights, which were assumed to represent the weights of the achene fruit wall, ranged from 1.43 grams/1000 to 4.24 grams/1000. A mean "embryo" weight for each family was calculated as the difference between mean full weight and mean empty weight. Such "embryo" weights varied from 0.51 grams/1000 to 2.28 grams/1000 achenes, and 15 percent to 47 percent of full achene weight. Although the differences among these family means could not be tested for significance in the present study, they do indicate another measure that should be examined in studies of phenotypic variation.

SUMMARY AND CONCLUSIONS

The M-type "wet film" soft X-ray procedure provides better resolution of embryo images in sycamore achenes than does the "instant paper" process. Four embryo classes, based on embryo appearance, can be distinguished from "wet film" radiographs: full, partial, abnormal, and empty.

Full and partial embryo classes of achenes are not significantly different for weight, percent germination, or rate of germination. But abnormal and empty classes are successively and significantly lighter, poorer in total germination, and slower in germination than the fulls and partials. Surface sterilization of achenes with dilute clorox enhances germination, reduces error variation, and is recommended for use in seed quality phenotypic studies.

Phenotypic variation in seed quality is large for all measures tested. No trends associated with latitude of seed source are evident for the sixteen families used. Hypocotyl length of the seedlings after seven days in the germinator, weights of full achenes, and weights of empty achenes appear the most promising of the traits studied as measures of phenotypic variation in sycamore seed quality.

Table 4.--Mother-tree family means and results of Duncan's New Multiple Range Tests[a] for sycamore seed weights

Mother-Tree Seed Lot	Achene Weights (gms./1000 achenes) Full(F)	Empty(E)	Calculated Embryo Wt. = F - E (gms./1000 achenes) F - E	100%(F-E)/F
South Transect[b]:				
M	4.61d	2.86D	1.74	38
P	4.03e	3.02D	1.10	25
B	2.75gh	2.05E	.70	26
F	3.43f	2.92D	.51	15
(Transect Mean)	(3.71)	(2.71)	(1.01)	(26)
Midsouth Transect:				
A	4.03e	3.11D	.92	23
J	2.44h	1.43G	1.01	41
N	2.75gh	1.55EF	1.20	43
O	1.98i	1.46G	.52	26
(Transect Mean)	(2.80)	(1.89)	(0.91)	(33)
Midnorth Transect:				
L	4.74c	3.52B	1.22	26
K	2.97g	1.58EF	1.39	47
G	2.69gh	1.84EF	.85	32
C	6.52a	4.24A	2.28	35
(Transect Mean)	(4.23)	(2.80)	(1.44)	(35)
North Transect:				
I	3.94e	2.84D	1.10	28
T	5.29b	3.51B	1.78	34
H	4.06e	3.17C	.89	22
S	2.92g	2.07E	.87	30
(Transect Mean)	(4.05)	(2.90)	(1.16)	(28)

[a] For a single trait, means not followed by the same letter are significantly different at the five-percent probability level.
[b] See transects in Figure 1.

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SESSION IV - DISEASES AND INSECTS

MODERATOR: ANTHONY E. SQUILLACE

IMPACT OF SEED INSECTS ON CONTROL-POLLINATED SLASH PINE CONES

Gary L. DeBarr, David L. Bramlett, and A. E. Squillace[1/]

Abstract.--Screening to exclude insects greatly increased the seed yields from self-, polycross-, and wind-pollinated slash pine cones. The sample cones were dissected and the cone scales identified as fertile or infertile. Based on radiographic examination, all ovules and seeds on the fertile scales were classified as (1) first-year aborted ovules, (2) second-year aborted ovules, (3) empty seed, (4) filled seed, (5) seedbug-damaged seed, or (6) Laspeyresia-killed seed. Caged wind-pollinated cones produced an average of 116 filled seeds per cone compared to 20 filled seeds produced by uncaged cones. Self- and polycross-pollinated cones produced 6 and 16 filled seeds per cone with screen wire cages but only 2 and 11 filled seeds per cone without cages. Most seed loss occurred as aborted ovules before seedcoat formation (wings but without seed). Both insect damage and pollination problems contributed to the high seed losses.

Additional keywords: Leptoglossus corculus, ovule abortion, Pinus elliottii, Tetyra bipunctata.

Poor seed yields from control-pollinated slash pine, Pinus elliottii Engelm., cones have plagued tree improvement workers for years. Snyder and Squillace (1966) reported an average of 28 sound seeds per slash pine cone from many years of controlled pollinations at Olustee, Florida, and Gulfport, Mississippi. Self pollination yielded one-eighth to one-sixth as much seed, while wind pollinations produced an average of 46 sound seeds per cone. Wakeley (1954) found that slash pine cones produced from 60 to 70 sound seeds per cone in good years and about half these numbers in poor years.

In a recent study DeBarr and Ebel (1974) demonstrated that the leaffooted pine seedbug, Leptoglossus corculus (Say) (Hemiptera: Coreidae), and the shieldback pine seedbug, Tetyra bipunctata (H.-S.) (Hemiptera: Pentatomidae), cause extensive seed losses in loblolly and shortleaf pines. The study described here was designed to determine how much seed yields from various types of slash pine pollinations might be increased by protecting against insect damage. In 1973 Squillace and Goddard began a study at Olustee, Florida, aimed at determining the extent of selfing in slash pine seed orchards through the use of gene-marker clones. Our entomological study was superimposed upon this study. To segregate insect-caused seed losses from pollination problems, small screen wire cages were used to protect cones.

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Using techniques described by Bramlett (1974), we also determined the maximum seed production potential for cones of the gene-marker clones. Then seed losses from self, polymix, and wind pollination were categorized and expressed in terms of seed potential. Finally, seed efficiencies were calculated from the yields of filled seed and the seed potential per cone.

MATERIALS AND METHODS

The ramets were located in six slash pine seed orchards owned by Brunswick Pulp and Paper Company, Florida Division of Forestry, ITT-Rayonier, Inc., University of Florida, and USDA Forest Service.[2/] Twenty-four clusters of female strobili were bagged for control pollinations on each of 8 gene-marker clones--16 for selfing and 8 for controlled crosses. An additional 8 unbagged wind-pollinated clusters were also designated. At the time of bag removal, one-half the clusters in each pollen treatment were caged. Thus, caged totals included selfed flowers on 8 shoots, poly-crossed flowers on 4 shoots, and wind-pollinated flowers on 4 shoots for each clone.

Protecting the strobili clusters from seedbugs during the months from pollination to harvest required the use of two types of small screen wire cages (DeBarr and Ebel 1974). Cages used to protect conelets were installed during the months of March and April 1973. In August of 1973, these cages were replaced with a second type that protected the strobili until harvest in September of 1974.

At collection, cones were placed in individual kraft paper bags. The sample cones were dissected and the cone scales identified as fertile or infertile (Bramlett 1974). Based on radiographic examination (DeBarr 1970), all ovules and seeds on fertile scales were classified as (1) first-year aborted ovules, (2) second-year aborted ovules, (3) empty seed, (4) filled seed, (5) seedbug-damaged seed, or (6) Laspeyresia-killed seed. Seed potential (2X the number of fertile scales) and seed efficiency (the number of filled seed divided by seed potential) were also calculated (Bramlett 1974).

RESULTS AND DISCUSSION

Ovule abortion.--First-year ovule abortion was the most frequent cause of loss (fig. 1). There are two known causes of first-year ovule abortion--lack of viable pollen and seedbugs. Unpollinated ovules abort several months after receptivity, but the seed wing continues to develop (Sarvas 1962). The presence of viable pollen, even if it is self pollen, assures continued ovule development. Only 23 ovules/cone in the wind-pollinated protected cones aborted during the first year, compared to 98/cone for selfs and 127/cone for the polymix strobili. Since insects were excluded from these cones, the most probable causes of ovule abortion relate to the supply or viability of the pollen or to the mechanisms of pollination. For example, any of the following conditions could produce the same effect: (1) pollen application did not coincide with the peak period of strobili receptivity, (2) inadequate supply

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2/ The assistance of these State and private organizations is gratefully acknowledged.

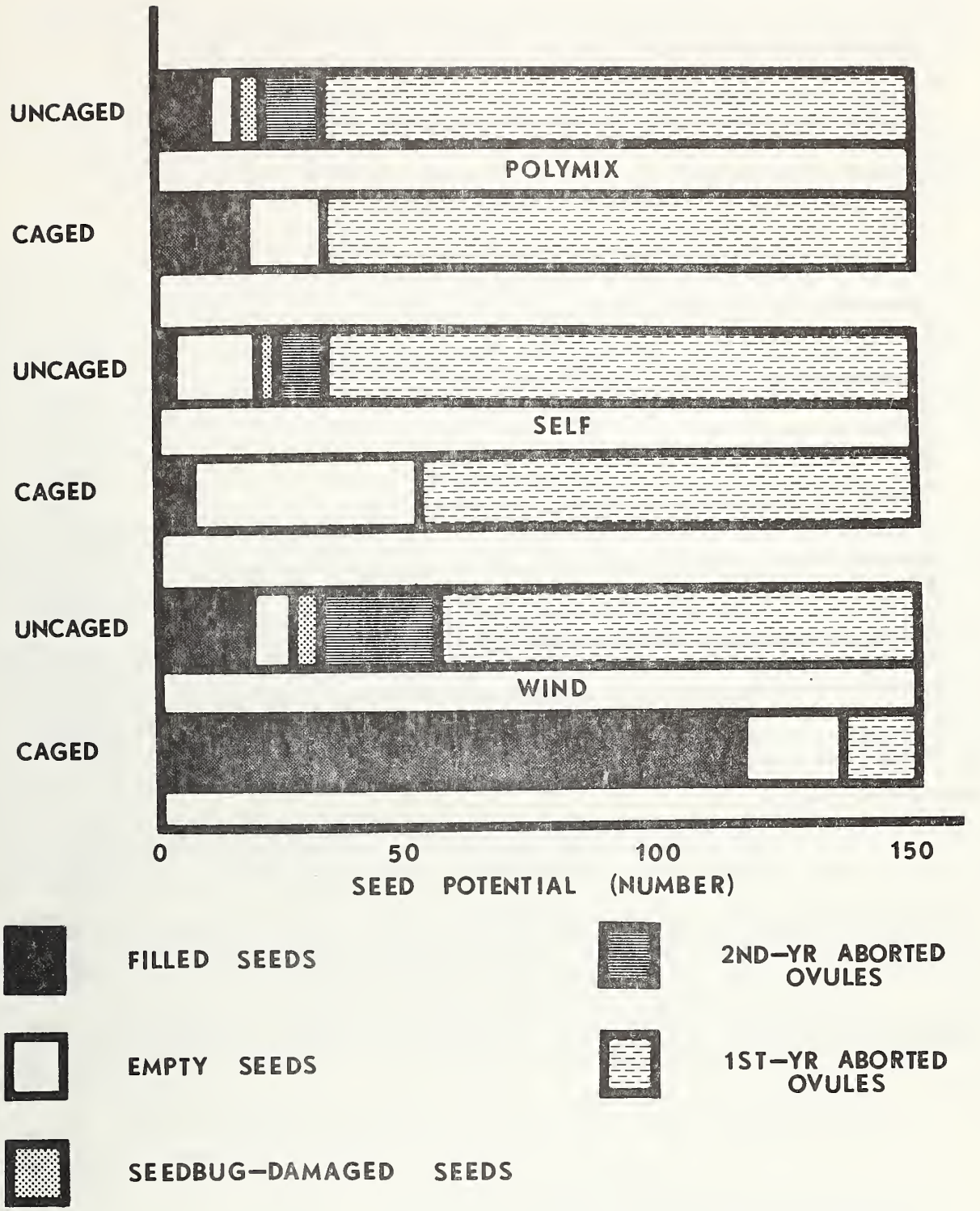

Figure 1.--Quantity and quality of seed harvested in 1974 from poly-cross-, self-, and wind-pollinated slash pine cones, with (caged) and without (uncaged) screening to exclude insects.

of pollen, (3) poor pollen distribution in the bag, or (4) nonviable pollen. In-vitro pollen germination was considered to be satisfactory (20 to 40 percent), but such germination may not always be a reliable measure of pollen vigor.

Seedbugs also destroyed first-year ovules (fig. 1). For all three pollination types, uncaged cones contained more aborted first-year ovules than caged cones. Eighty-six percent of the ovules in the caged wind-pollinated strobili were still healthy at the beginning of the second growing season, compared to only 64 percent in the uncaged wind-pollinated strobili.

Ovule abortion also occurred early in the second year of seed development. These ovules, destroyed before the formation of a mature seedcoat, appeared in mature cones as collapsed, resinous, or flattened seed. Caging tests have proven that abortion of second-year ovules in slash pine, Virginia pine, P. virginiana Mill., (Bramlett and Moyer 1973) and loblolly pine, P. taeda L., (DeBarr 1974) is caused exclusively by insects. In the present study, caged cones averaged less than 1 second-year aborted ovule per cone regardless of the pollen treatment, compared to 8, 12 and 23 second-year aborted ovules in the uncaged self-, polymix-, and wind-pollinated cones, respectively.

Seed quality.--In all but the caged wind-pollinated cones, more than two-thirds of the seed potential was lost to ovule abortion by the time of fertilization early in the second season of strobili growth. Normally, fertilized ovules develop a stony seedcoat and become filled seeds. Under self pollination, there is a high probability of a recessive combination of embryonic lethals. If this occurs, the integuments continue to develop, while the embryo and female gametophyte degenerate, forming an empty seed. Eighty-six percent of the seeds from the self-pollinated cones protected with cages were empty, compared to only 14 percent of the wind-pollinated seeds from protected cones. For all three pollen types, protected cones yielded a higher percentage of filled seeds than unprotected cones.

From 5 to 11 percent of the seeds from the uncaged cones of the three pollen types were classed as seedbug damaged on the radiographs. In contrast, an average of less than 1 seed per caged cone was classed as seedbug damaged.

Strobili survival.--Conelet and cone abortion were not measured directly in our study but the numbers of conelets pollinated and the numbers of cones harvested were counted. Caging increased overall survival by almost one-third (table 1). Snyder and Squillace (1966) reported a long-term average of 40 percent of the cross-pollinated slash pine flowers surviving to maturity. Our uncaged value of 47 percent is within the range of their observations.

Table 1.--Percentage of flowers maturing into cones--slash pine, 1974

Protection	Pollen			Overall Average
	Wind	Self	Polymix	
Caged	76	63	55	68
Uncaged	56	33	45	47

Seed efficiency.--Bramlett (1974) found that the average seed potential for sample cones from a slash pine seed orchard was approximately 170 seeds per cone. The seed potential for our 8 gene-marker clones averaged 152 seeds per cone. Seed efficiency was least for self-pollinated strobili and greatest for the wind-pollinated strobili. Caging greatly increased the seed efficiencies for all three pollen types. An efficiency of 72 percent was obtained for the wind-pollinated caged cones.

CONCLUSIONS

Most seed loss occurred as aborted ovules before seedcoat formation. Both insect damage and pollination problems contributed to the high seed losses. Our yields from caged wind-pollinated cones demonstrate that it is possible to obtain a seed efficiency of 72 percent seed potential when insect damage is prevented. If pollination problems can be overcome, then insect protection would assure similar seed efficiencies for cross-pollinated cones. Perhaps geneticists and tree physiologists should reexamine techniques used in control pollinations.

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CONE AND SEED INSECTS--SOUTHERN PINE BEETLE: A CONTRASTING IMPACT ON FOREST PRODUCTIVITY

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Abstract.--As seed orchard production in the South increases, a commensurate recognition of seed losses due to insect attack has developed. It is now evident that value losses resulting from cone and seed insects can be compared with the destruction caused by the southern pine beetle (Dendroctonus frontalis Zimm.). While the value losses are comparable, the impact of cone and seed insects on intensive forest management efforts is nearly invisible to all but the tree improvement practitioner. This situation presents a particularly difficult challenge to the researcher as he strives to obtain resources and support to develop control systems which appear attainable with an intensive research and development program of rather finite scope and duration. A similar conclusion is not readily apparent for the research efforts directed toward control of the southern pine beetle. The forestry enterprise is constantly confronted with this dilemma of having to allocate limited resources to investment in production for the long term while simultaneously responding to short-term pressures for these resources which can be spectacular as exemplified by the southern pine beetle attacks.

Additional keywords: Seed value, economic impact, management priorities

INTRODUCTION

First-generation forest tree seed orchards of southern pines are now approaching their full productive potential. Recent reports have shown investments in tree improvement activities to be very profitable. The value of genetically improved seed is surprisingly high when expressed in terms of the present worth of the additional wood available at time of harvest (Porterfield, 1974; Zobel, 1974). However, efficient production of the needed quantities of improved seed is not accomplished without difficulty. Cone and seed insects annually destroy a very significant proportion of the genetically improved seed crop. The dollar value of seed losses is conservatively estimated to be in excess of 25 million dollars annually for the southern forestry enterprise. These heavy losses would seem to be avoidable as the seed orchard insect problems are amenable to solution.

Just a few years ago seed orchard insect pests were known by only a few research entomologists. They are now considered to be the most serious problem confronting seed orchard programs in the South. Even so, the abovementioned financial impact on long-term forest productivity is largely hidden from all but those actively involved with forest tree improvement because it is a loss in potential production, not one easily seen and understood from observing dead and dying trees. In marked contrast is another forest insect pest, the southern pine beetle (Dendroctonus frontalis Zimm.). With estimates of damage in epidemic years exceeding 40 million dollars, the southern pine beetle has generally been considered the most economically important insect pest of southern forests.

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Characteristic damage is equally obvious to the forester, the small woodlot owner, and the suburban dweller. The immediate impact, both financially and aesthetically, has historically resulted in public pressure to develop emergency pest control programs for this destructive enemy of the forest. Of recent note is a multimillion-dollar special appropriation by the federal government aimed at developing long-sought-after, and to date elusive, control measures for the southern pine beetle.

It is a constant dilemma for the long-term, high-risk forestry enterprise to properly apportion the limited resources available. Priorities must be set among efforts directed toward minimizing immediate losses and investments in research and development expected to increase productivity in the future. In an enterprise which is frequently, and many times unavoidably, occupied with crises management, it is not unexpected that the southern pine beetle has received a significant share of the available resources. Yet this is a trend which must be modified if the South is to meet long-term production goals set for the third forest (Anonymous, 1969).

CONE AND SEED INSECTS

Major Insects and Their Habits

The larvae of coneworms (Dioryctria spp.) are extremely destructive pests of southern pine seed crops. Among the five species of coneworms, D. amatella (Hulst) is apparently most widespread and attacks most of the major southern pine species (Goolsby, et al., 1972). The coneworm larvae feed primarily on first- and second-year cones but also on buds, shoots and bases of overwintering cones. Damage is caused by boring into the cone, and, as feeding progresses, the interior of the second-year cone is hollowed out. A damaged cone is all or partially browned prematurely and exhibits one or more larvae entrance holes which are usually clogged with frass and/or a resinous mass. Feeding on first-year conelets can cause complete conelet mortality. Coneworms often have multiple generations per year, the number being dependent on the particular species of insect and latitude. Each generation attacks previously undamaged tissue.

Where chemical control of coneworms has not been practiced, damage has been assessed at 20 to 40 percent of the second-year slash pine (Pinus elliottii Engelm.) cone crop (Merkel, et al.). Recent studies in loblolly pine (Pinus taeda L.) conducted by the N. C. State Cooperative Tree Improvement Program have shown 20 to 30 percent destruction of the second-year cone crop to be common. Little has been reported with respect to coneworm destruction of first-year conelets, yet losses in the first year may be as much as double those of maturing second-year cones.[1/] It is very clear that an economically significant proportion of the orchard seed crop can be destroyed annually if programs designed to control coneworms are not developed.

The leaf-footed bug (Leptoglossus corculus Say) and shield-back bug (Tetyra bipunctata H. and S.), both known as seed bugs, are serious pests in all southern pine seed orchards (DeBarr, G. L., 1967). These bugs feed on maturing seed from outside the cone, using a stylet or sucking mouth part to penetrate the cone scales. Enzymes are secreted which digest the developing seed tissues, which are in turn sucked back through the stylet. Because of their feeding habit, damage caused by seed bugs is nearly always imperceptible without magnification.

[1/] Unpublished report from Louisiana State Seed Orchard in DeRidder, La., 1973; and observations in seed orchards of the N. C. State Cooperative

Seed bug damage is frequent on both first-year conelets and maturing second-year cones. In both the first and second year the entire cone may abort when tissue destruction is extensive. Less intensive feeding will result in complete seed destruction, empty seed or partly filled seed. Because seed bug damage is not readily observable, much of the seed and cone damage has been attributed to causes such as inadequate pollination or physiological complications. However, caged conelets subjected to seed bug feeding for as little as a week suffered from 61 to 100 percent abortion, depending on time of year and pine species involved. In the second year of development, loblolly and shortleaf (P. echinata Mill.) cones protected from seed bugs yielded 2-1/2 and 12 times, respectively, more filled seed than unprotected cones (DeBarr and Ebel, 1973). Seed bugs may be the seed orchard managers' most troublesome pest.

There are other insects which collectively can cause significant reductions in orchard seed production. The seed worm, Laspeyresia spp., eggs are laid on second-year cones. Upon hatching, the larvae bore through cone scales into the maturing seed and tunnel from seed to seed within the cone. Not all seed within an infested cone are lost; damage is most common on lower branches of the tree. Pine tip moths (Rhyacionia spp.) find open-grown seed orchard trees ideal for attack. The insect larvae bore into developing shoots of most southern pines. The terminal portion of the shoot which is killed often contains the embryonic reproductive structure. Damage to longleaf (Pinus palustris Mill.) and slash pines is infrequent and control of this insect on loblolly, Virginia (Pinus virginiana Mill.) and shortleaf pines is possible with approved systemic insecticides. The pine flower thrip (Gnophothrips fuscus Morgan) causes significant damage to slash pine female strobili during the very short interval between emergence from the bud and completion of pollination. However brief the damage period, thrips can destroy over 50 percent of the potential slash pine cone crop in a given year if they are not controlled (DeBarr, 1969).

Control

Registered and effective controls for cone and seed insects do not generally exist. Notable exceptions are the systemic insecticide Thimet(R) which is used to control tip moth and the foliar spray Guthion (R) which has restricted registration for control of Dioryctria spp. on slash pine. Registration of Guthion(R) is currently under consideration for expansion to all pine seed orchards. Even so, the level of sophistication for cone and seed insect control is minimal. Many additional chemicals need to be examined for efficacy and there is a need for studies directed toward proper timing, dosage, residual activity of the chemicals and application techniques as they relate to insect behavior. Resources to support these critically needed studies have been virtually nonexistent to date.

Economic Impact of Seed Losses

Wood production per acre is expected to increase significantly both in quantity and quality with the use of genetically improved regeneration stock (Zobel, 1974). The amount of growth improvement from first-generation seed orchard seed is conservatively estimated to be 15 percent at time of harvest or rotation age. The value of a pound of loblolly orchard seed can range from $159 to $794 when expressed in terms of the present value of 15 percent additional wood volume produced at the time of harvest (see Table 1). For slash pine, the present value of a pound of seed is 75 percent that of loblolly because 6000 plantable seedlings are generally obtained as compared to 8000 per pound from loblolly. These calculations require assumptions with respect to seedling yields per pound of seed,

plantation spacing, growth rate, interest rates and projected stumpage values at rotation age as shown in the table. All assumptions are realistic. The per-pound seed values do not reflect the difference between seed production costs for the orchard and costs for wild seed on the open market. However, recent estimates show that the additional cost of producing orchard seed is in the order of 5 to 10 dollars per pound, an insignificant amount when contrasted to the high values of improved seed. Conversely, the present seed value estimates do not reflect any improvement in tree quality. Although quality improvements are difficult to quantify, they do increase product value, thus the present value of a pound of seed, by an economically significant amount estimated to equal volume gains.

With the value of a pound of seed determined, the economic impact of cone and seed insects can be calculated as the product of the pounds of seed destroyed and the dollar value of each pound. Numerous impact estimates are presented for a representative 40-acre loblolly orchard at three rates of orchard production, 20, 30 and 40 pounds of seed per acre (Tables 2, 3 and 4). The annual reduction in net worth for an organization having such an orchard can range from $25,440 to $508,160, depending on orchard production potential, plantation site quality, and stumpage value 25 years in the future. A reasonable, although probably conservative, estimate of average annual economic losses from insects would be $128,520 for a 40-acre loblolly seed orchard. Southwide, the current value of annual losses could be expected to range from $8,083,908 to $40,419,540 for all loblolly and slash pine orchards combined (Table 5). An approximate Southwide average would be 20 to 25 million dollars in present value of future timber lost per year.

Table 1. Present value of the additional wood obtained from a pound of genetically improved loblolly seed

Stumpage Value ($/cord at harvest 25 years in future)	Present Value of Seed Base growth in cords/acre/year		
	1.0	1.5	2.0
20	$159	$238	$318
25	198	297	397
30	238	357	476
40	317	476	637
50	397	595	794

Assumptions:

1. One pound of seed produces 8000 plantable seedlings.
2. Trees planted at 8' x 10' spacing--approximately 550/acre (1 lb. of seed plants 14.5 acres).
3. Rotation age is 25 years.
4. Genetic gain is 15%.
5. Interest rate is 8%.

Table 2. Present value of 20% seed loss from a 40-acre loblolly seed orchard with potential yields of 20, 30 and 40 pounds of seed/acre/year

Base Growth (cords/acre/year)	Stumpage Value ($/cord at harvest)	Present Value of Seed Lost Seed yields/acre of orchard in lbs. 20	30	40
1.0	20	$25,440	$38,160	$50,880
	25	31,680	47,520	63,360
	30	38,080	57,120	76,160
	40	40,720	76,080	101,440
	50	63,520	95,280	127,040
1.5	20	$38,080	$57,120	$76,160
	25	47,520	71,280	95,040
	30	57,120	85,680	114,240
	40	76,160	114,240	152,320
	50	95,200	142,800	190,400
2.0	20	$50,880	$76,320	$101,760
	25	63,520	95,280	127,040
	30	76,160	114,240	152,320
	40	101,920	152,880	203,840
	50	127,040	190,560	254,080
Total pounds seed lost annually		160	240	320

Table 3. Present value of 30% seed loss from 40-acre loblolly seed orchard with potential yields of 20, 30 and 40 pounds of seed/acre/year

Base Growth (cords/acre/year)	Stumpage Value ($/cord at harvest)	Present Value of Seed Lost Seed yields/acre of orchard in lbs. 20	30	40
1.0	20	$38,160	$57,240	$76,320
	25	47,520	71,280	95,040
	30	57,120	85,680	114,240
	40	76,080	114,120	152,160
	50	95,280	142,920	190,560
1.5	20	$57,120	$85,680	$114,240
	25	71,280	106,920	142,560
	30	85,680	128,520	171,360
	40	114,240	171,360	228,480
	50	142,800	214,200	285,600
2.0	20	$76,320	$114,480	$152,640
	25	95,280	142,920	190,560
	30	114,240	171,360	228,480
	40	152,880	229,320	305,760
	50	190,560	285,840	381,120
Total pounds of seed lost annually		240	360	480

Table 4. Present value of 40% seed loss from 40-acre loblolly seed orchard with potential yields of 20, 30 and 40 pounds of seed/acre/year

Base Growth (cords/acre/year)	Stumpage Value ($/cord at harvest)	Present Value of Seed Lost Seed yields/acre of orchard in lbs. 20	30	40
1.0	20	$50,880	$76,320	$101,760
	25	63,360	95,040	126,720
	30	76,160	114,240	152,320
	40	101,440	152,160	202,880
	50	127,040	190,560	254,080
1.5	20	$76,160	$114,240	$152,320
	25	95,040	142,560	190,080
	30	114,240	171,360	228,480
	40	152,320	228,480	304,640
	50	190,400	285,600	380,800
2.0	20	$101,760	$152,640	$203,520
	25	127,040	190,560	254,080
	30	152,320	228,480	304,640
	40	203,840	305,760	407,680
	50	254,080	381,120	508,160
Total pounds of seed lost annually		320	480	640

Table 5. Present value of seed losses from insect attack for the combined acreage of slash and loblolly pine seed orchards in the South having seed yield potential of 30 lbs./acre/year

Stumpage Value ($/cord at harvest 25 years in future)	Present Value of Seed Lost Annually 20% Insect Loss	30% Insect Loss	40% Insect Loss
20	$8,083,908	$12,125,862	$16,167,816
25	10,087,902	15,131,853	20,175,804
30	12,125,862	18,188,793	24,251,724
40	16,167,816	24,251,724	32,335,632
50	20,209,770	30,314,655	40,419,540

Base growth rate assumed to be 1.5 cords/acre/year

Slash pine orchards total 2668 acres
Loblolly pine orchards total 3360 acres

Overall Total 6028 acres

From: Tree Seed Orchards, Forest Service, U. S. D. A., 1974

All insect damage valuations assume that an organization must substitute wild seed for each pound of seed lost in order to meet regeneration needs. Alternatively, if an organization has a surplus of seed, the calculations assume fair market sale values equal to the present values calculated for a pound of

seed. These assumptions appear realistic because few, if any, organizations in the South have a surplus of seed either wild or improved. The present scarcity of wild seed is indicative of future conditions. Mature seed-bearing stands are rapidly being harvested and replaced by vigorous plantations which will be harvested on short rotations prior to seed production in meaningful quantities. In the near future almost all seed for the very large regeneration programs will by necessity be produced in seed orchards. As advanced-generation orchards come into production the seed value and the impact of insect damage will increase dramatically because of greater genetic gain. We must learn to minimize seed losses now or pay a high price in the years to come.

The alarming aspect of seed destruction by insects in seed orchards is that the impact will not be evident until 25 or so years from now, at the time of harvest of plantations now being established. All recent projections indicate that demand for wood in the year 2000 will exceed current projections of supply. The need for immediate control of cone and seed insect populations in our southern pine seed orchards is critical. Without seed, there will be no regenerated forests to protect from other pests.

SOUTHERN PINE BEETLE

The Insect and Its Habits

The southern pine beetle (SPB) has historically been known as the most destructive insect pest of southern pines. The beetle normally attacks weak or stressed trees, but can kill very vigorous, healthy trees during epidemic outbreaks. Population buildup and the associated destruction of the southern pine forest by the SPB is very cyclical. Epidemic populations have been known to develop rapidly following periods of prolonged drought or very mild winters; at other times populations grow to epidemic size for no apparent reason. Except during epidemics the SPB is difficult to find; this frequent scarcity has presented great difficulty in controlled study of this insect.

The SPB beetle attacks a tree by boring into the bark and eventually the phloem and cambial tissues. The beetles construct S-shaped tunnels in and under the bark and are believed to kill the tree by girdling and the introduction of blue-stained fungi. Eggs are laid within the crisscrossing tunnels which develop into larvae of the succeeding generation of adults. The life cycle of the SPB is usually completed within 30 to 50 days; depending on latitude, as many as five to six generations may be produced annually (Thatcher, 1960).

Each brood adult bores its own emergence hole and flies to a new site of attack. The parent adults often exit from a host tree when the brood is still in the larval stage. It may reattack the same tree or attack uninfested trees at varying distances from the original attack. Trees are killed in groups that may vary from a few to many thousands in size. In large forested areas, damage spots are often located by aerial spotting of yellowing or brownish-red trees which are dying or dead. When foliar symptoms of insect attack become evident, the beetles have usually left the tree, making control most difficult.

Control

Effective control of epidemic outbreaks of the SPB is complicated by the characteristic infestation of localized stands of pines in an unpredictable pattern over a broad area of forest. Even with remote sensing methods, timely location of active population centers is often difficult, since the SPB is prone to move to a new area by the time damage symptoms are confirmed.

Chemical spray programs have generally proved to be ineffective in checking population buildup of the SPB (Coulson, et al., 1972). Even the traditional salvage cutting coupled with a BHC (benzene hexachloride) spray effort could not be shown as statistically effective during a beetle buildup in east Texas. Use of fast-acting herbidides containing cacadylic acid (dimethyl arsenic acid) injected into recently attacked trees has resulted in as much as 97% brood reduction (Ollieu, 1969). However, treatment success was considerably reduced if trees were not treated within 3-4 days of the initial attack. Logistic difficulties limit this method as an effective control. Recent research in control techniques has concentrated on methods of population manipulation by using attractants in conjunction with either chemical control or trapping. Although promising, these methods have yet to be proven economically feasible and biologically effective for large-scale operational control. Recent federal appropriations have been approved which will support an extensive program for developing these and other SPB control measures.

The Economic Impact of the Southern Pine Beetle

The immediate impact of SPB-killed trees can be most dramatic in both a financial and aesthetic sense. It is most often the mature, fully grown, merchantable trees which are attacked. The subsequent mortality can result in considerable financial loss to the industrial forestry concern and the small private owner. In addition, there is aesthetic degradation of parks, recreation areas and residential property, including the attractive tree-lined streets of southern cities.

Although salvage operations are frequently extensive and costly during periods of epidemic SPB attack, such efforts are at best means of minimizing losses. Salvage operations resulting from SPB kill are commonly undertaken on a very large scale by forest industry, yet it is done at a considerable cost. Simply locating the beetle-killed areas can be a continuous and costly task for a large industrial forest landowner. The timber killed by beetles is subject to rapid degrade, first by blue-stain infection and ultimately complete decay results from the action of other wood-destroying insects and fungi. Thus salvage must be fast and continuous if losses are to be minimized.

Sometimes the dead timber is not readily accessible and salvage requires construction of new and previously unplanned roads. Such road construction is often impossible or impractical before the timber undergoes serious degrade or actual decay. Even if accessibility is not a factor, the small scattered clumps of mortality do not present an attractive logging chance. The manager is then forced to either offer the timber at an extremely low stumpage price or to cut a larger section of the stand, including much healthy timber. When the latter course is followed, the forest manager can adversely alter cutting budgets to the extent that years are required to properly rectify the management plans. All of this is extra, unplanned work occurring at unpredictable times and at a very high cost. All too frequently salvage cannot be accomplished and the timber killed is a total loss.

The small woodlot owner experiencing SPB kill is faced with an even more serious dilemma. He can simply forego salvage and suffer the loss or he can harvest enough of the stand, including the infested trees, to make the logging worthwhile. Timber sales resulting from salvage cuts often occur at a time when open market stumpage prices are depressed due to an oversupply of such wood, causing the small landowner to lose no matter what course of action he follows.

The homeowner with shade trees killed by the SPB is seldom able to recoup any losses from salvage cutting. In fact, he must frequently pay a substantial fee to have dead trees removed. Residential property can suffer serious devaluation

if a significant portion of the trees is lost. The aesthetic losses resulting from the mortality of large trees in parks and recreation areas is very difficult to assess. Yet in such areas we all may experience a very distinct, albeit intangible, reduction in the quality of our recreational experience.

An effort has been made to estimate and quantify in economic terms the Southwide losses resulting from SPB attack. These data (Table 6) have been collected for a 14-year period extending from 1960 through 1973 by the Southern Forest Insect Work Conference Committee on Losses Caused by Forest Insects. The present value (year 1975) of the loss estimates ranges from a low of $423,500 to a high of $48,473,600; the 14-year average is nearly 10 million dollars per year. The committee has cautioned that these data are incomplete. However, these data should allow assessment of the relative impact of SPB damage as compared to other forest insects. This assumption is given credence from the enormous magnitude of loss, particularly in epidemic years such as 1973. The southern pine beetle deserves its reputation as one of the most economically important pests in the southern forest.

Table 6. A yearly assessment of losses sustained Southwide from southern pine beetle attack: 1960 through 1973

Year	Annual Estimate of Damage Assessment 1/	Year	Annual Estimate of Damage Assessment 1/
1960	$6,056,100	1967	$228,800
1961	1,259,900	1968	664,310
1962	4,554,300	1969	1,740,400
1963	1,094,000	1970	1,296,000
1964	553,300	1971	4,143,000
1965	701,870	1972	28,802,700
1966	974,920	1973	41,558,300
		Total	$93,607,900
		Avg./Year	9,686,200

1/ From reports of the Southern Forest Insect Work Conference Committee on Losses Caused by Forest Insects

CONE AND SEED INSECTS VERSUS THE SOUTHERN PINE BEETLE-- A DISCUSSION OF CONTRASTS

It is the objective of this discussion to show, by contrasting the value losses resulting from cone and seed insects to those of the SPB activities, that the destruction of seed orchard crops is of critical importance. Damage from cone and seed insects can be of the same order of magnitude as damage from the worst known insect pest of the southern forest, yet there is a distinct lack of general awareness and knowledge about these long-term losses. This situation must be corrected.

The most recent epidemic outbreak of SPB (1972-1975) has raised the public concern over this pest to an all-time high. As a result, federal support in the millions of dollars has become available for a five-year program directed toward

research and development of SPB control measures. Certainly the problems are serious and the need for additional research effort cannot be denied. However, many have questioned whether significant positive results can be expected from such a crash program. Research on control of this insect has been underway for at least two decades and positive results have been elusive. Recent concern over environmental consequences of extensive insecticide applications has greatly reduced that option. The development and evaluation of less traditional control systems is threatened by the unpredictable likelihood of complete SPB population collapse. It is not possible to study means for operational control of epidemic conditions after the insect has virtually disappeared.

The support for research and development of cone and seed insect control has always been limited and has not increased commensurate with its need. In contrast to recent appropriations for SPB research, cone and seed insect work is at the present time virtually fundless. This situation exists despite an excellent probability of developing very effective and operationally feasible control measures with a research program that is relatively moderate in size and duration. Similar pest problems have been solved in horticultural crops such as fruit and nut orchards. A suggested experimental program to attack the problem would include:

1. Select the most promising insecticide(s) on the basis of laboratory and field screening.
2. Determine the proper timing, dosage and application method of the insecticide(s) on the basis of the insect life cycle(s).
3. Operationally demonstrate the effectiveness of control methods with regionwide studies.
4. Continue studying the biology of the insect(s).

Development of control techniques for cone and seed insects is lacking in complexity when compared to the problems encountered with the SPB. Controls are to be concentrated on limited acreage, under 10,000 total. In addition, cone and seed insect populations are more predictable; they do not undergo the cyclical extremes ranging from epidemic outbreaks to virtual disappearance that is so characteristic of the SPB.

Some have argued that research support for cone and seed insect control should be the responsibility of forest industry. The rationale has been that industries own the seed orchards and they will derive the benefits from insect control. This argument is not justified. Latest statistics indicate that 51% of the southern seed orchard acreage is under the control of state and federal governments. The seed and subsequently the trees produced from these orchards will be used to regenerate public and private lands alike. In the long run, increasing the productivity of such plantings will benefit the consumer at large by increasing wood supply and thus reducing the price of wood products. Control of cone and seed insects as an integral part of seed orchard management is an activity which can benefit all, including forest industries.

A final contrast involving the SPB versus cone and seed insects has the characteristics of a continuous dilemma confronting managers of the forestry enterprise. By virtue of the long-term nature of forest production, long-range planning is a necessity. However, forestry organizations are never immune to short-term pressures which demand the best available crisis management. The dilemma is to strike a proper balance in setting priorities among the long- and short-term demands. The control of SPB with its highly visible and abrupt impact is a current problem needing immediate attention. The impact of cone and seed insect attack will generally be realized in the long term. Yet if serious financial losses and wood

shortages with higher prices are to be avoided in the future, investment in research and development of control measures must be initiated today. With limited resources available, the priority decisions are never easy. It would not be appropriate to advocate increased funding of cone and seed insect research at a major expense of SPB efforts. It is proper, however, to recognize the importance of cone and seed insect destruction, and for each organization to adjust priorities in a manner that will balance the expenditure of resources among the short-term demands and the long-term investment in increased forest production.

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VARIABILITY OF *CRONARTIUM FUSIFORME* AFFECTS RESISTANCE BREEDING STRATEGIES

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Abstract.--Variable response of open-pollinated slash pine families to diverse inocula indicate extensive pathogenic variability in *Cronartium fusiforme*. Inocula from field-infected members of a resistant slash pine family were more virulent on seedlings of the same parent than inocula representing the general rust population. Hence, the raw material and capacity for shifts in virulence are present. The rates and importance of such shifts are uncertain, but *C. fusiforme* will be subjected to increasing selection pressure as plantings of resistant pines expand. The potential threat of increased virulence must be considered in breeding and deploying resistant pines. Procedures for enlarging the number and variety of resistant selections in seed orchards are suggested.

Additional keywords: *Pinus taeda*, *P. elliottii* var. *elliottii*, virulence, fusiform rust.

Fusiform rust, caused by *Cronartium fusiforme* Hedgc. and Hunt ex Cumm., limits productivity of loblolly (*Pinus taeda* L.) and slash (*P. elliottii* var. *elliottii* Engelm.) pines over much of their commercial ranges. The disease, largely a curiosity until 1930, has become increasingly widespread and damaging (Dinus 1974). Resistance breeding is a promising tactic for reducing losses to rust (Rockwood and Goddard 1973, Stonecypher et al. 1973), but development and deployment of resistant pines involves some risk. *C. fusiforme* has proven highly variable, and selection pressures imposed by resistant plantings may increase the frequency of virulent forms.

The present paper summarizes available information concerning pathogenic variability and shifts in virulence and suggests means for coping with these problems.

PATHOGENIC VARIABILITY

An early experiment (Snow and Kais 1970) provided the first direct evidence of pathogenic variability in *C. fusiforme*. Two open-pollinated families each of loblolly and slash pine were inoculated artificially with three collections of *C. fusiforme* from each of five widely separated areas. Families considered susceptible in previous field tests proved susceptible

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to all inocula. In contrast, loblolly pines from the resistant family were moderately resistant, on the average, to inocula from all areas but varied in their response to individual inocula from each area. Seedlings from the resistant slash pine family were even more variable in their responses. They were moderately resistant to Texas, Mississippi, and North Carolina inocula but susceptible to those from Alabama and Florida.

Much additional information concerning the occurrence and extent of pathogenic variability has since been accumulated. In three experiments, we evaluated the responses of 14 open-pollinated slash pine families to diverse inocula (Snow et al. 1975). In each experiment the inocula x family interaction was significant. Most families were quite variable in response; they proved susceptible to some inocula and resistant to others. Only four families were susceptible and two families were resistant to all inocula. These results demonstrated variability among inocula from widely separated areas, among inocula from different locations within each area, and also among inocula from individual galls.

SHIFTS IN VIRULENCE

The extensive variability described above is the product of past evolution but more importantly is also the raw material for future change. To the extent that resistant pines are planted, future change will be man-directed, and therein lies the risk. Extensive or repeated planting of pines with only one or a few types of resistance may lead to an increased frequency of virulent forms of C. fusiforme.

Such shifts have been observed in response to the planting of at least one resistant slash pine family, one whose responses proved highly variable in the experiments previously described. In a recent test (Snow et al., in prep.), inocula specific to the particular family--family specific--were collected from nine galls on field-infected members of that family in two open-pollinated progeny tests. Random inocula--samples representing the general rust population--were collected from nine galls on woods-run slash pines outside, but within 1 mile of, the same plantations. Collections from each gall were processed separately and used to inoculate open-pollinated seedlings of the same family.

Two random inocula caused no galls, two others infected only one seedling each, and only one approached the family specific inocula in virulence (fig. 1). With the random inocula, percentages of seedlings with galls ranged from 0 to 54 and averaged only 17 percent. In contrast, average infection over all family specific inocula was 77 percent. This significant fourfold difference indicates that the frequency of forms capable of infecting seedlings of this family was increased. Moreover, variation among family specific inocula was sizable, ranging from 52 to 94 percent. Hence, even further selection seems possible.

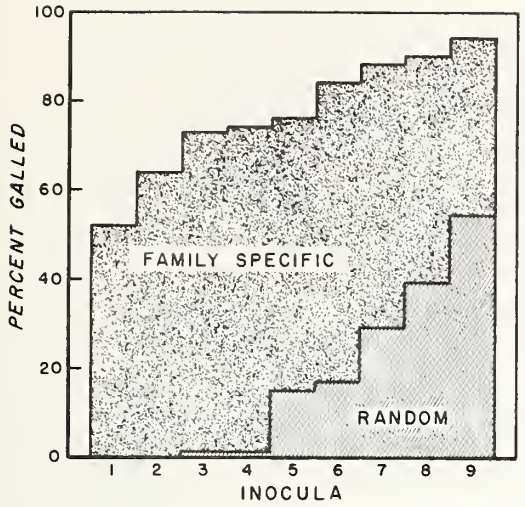

Figure 1.--Percentage of seedlings in a resistant slash family galled 6 months after inoculation with nine inocula from field-infected offspring of the same parent (family-specific) and nine random inocula. Inocula are ranked in order of increasing virulence.

C. fusiforme, then, can adapt in response to resistant hosts. Existing plantings of resistant pines are small and scattered. Resistant materials are just now becoming available for extensive use. As the number and area of resistant plantings enlarge, C. fusiforme will be subjected to increasing selection pressure. We do not see drastic shifts as imminent, but we do visualize at least gradual erosion of resistance unless the potential for change is considered in resistance breeding programs.

Currently, progenies from rust-free parents are tested either in the field near sites to be reforested or by artificial inoculation with C. fusiforme collected from such sites. These procedures identify resistant parents but provide little information about the stability of resistance or different types of resistance.

To acquire such information, we suggest that present testing practices be supplemented. First, the most resistant parents now available should be tested against a broad array of inocula. Minimally, such a array should sample all likely planting sites; for example, all eastern Coastal Plain sites managed by a given agency. Indeed, some agencies have already expanded the number and distribution of their progeny tests. Ideally, the array of inocula should be as extensive as possible. The most desirable parents will be those whose progeny are least variable in their response to diverse inocula. The resistance of such parents is least likely to be overcome by extant virulent forms or to cause future shifts in virulence.

Second, individual resistant families should be tested against inocula from field-infected members of the same families and also against inocula representing the general rust population. Families that respond similarly to family-specific and random inocula seem least likely to provoke selection for increased virulence.

Third, to identify parents with different types of genetic resistance, we suggest cross-inoculation among families that have proven most promising. Inocula should be collected from field-infected members of each family and systematically applied to seedlings of that particular family and all others. This systematic cross-inoculation would indicate if a given set of parents has different genetic bases for their resistance.

The ideal resistance breeding program should utilize a large number of parents, each with one or more types of resistance. Should such parents be few in number, steps should be taken to broaden the genetic base. Selection and testing of new parents must be a continuing process. The primary purpose of continued selection is acquisition of additional resistance genes, but a broad genetic base will facilitate improvement of other traits and will also lessen the probability of encountering problems with yet other pests in the future.

In the absence of more complete information, the above suggestions should enable us to enlarge the number and variety of resistant parents in seed orchards. If resistant pines are to be planted with confidence, however, further research is needed on the genetics of both resistance and virulence. Reactions contributing to resistance must be better characterized and their inheritance patterns quantified. Mechanisms providing for genetic change in C. fusiforme as well as maintenance and spread of forms with increased virulence must also be clarified.

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IMMEDIATE GAINS IN FUSIFORM RUST RESISTANCE IN SLASH PINE FROM ROGUED SEED PRODUCTION AREAS IN SEVERELY DISEASED PLANTATIONS

R. E. Goddard, R. A. Schmidt and F. Vande Linde[1/]

Abstract.--Progenies (families) of open-pollinated Pinus elliottii var. elliotii representing low (population A) and high (population B) selection pressure for resistance to Cronartium fusiforme were evaluated for rust resistance in field tests at three geographic locations. Population A had average rust incidence of 85, 63, 47 and 14%, compared to 61, 36, 26 and 6% for population B in the same tests. Expressed as an infection ratio, population B had approximately one-half (0.44-0.72) the percentage rust of population A. The frequency of percent rust by families indicated a normal distribution for both populations. These data show that progenies from population B are more resistant than those of population A in three geographic locations, and therein support the contention that seed from rogued seed production areas located in high rust incidence areas can provide substantial short range gains in rust resistance.

Additional keywords: Pinus elliotii, Cronartium fusiforme, intensive selection, tree improvement.

Fusiform rust, caused by the fungus Cronartium fusiforme Hedge. and Hunt ex Cumm., is the most serious disease of slash pine (Pinus elliottii var. elliottii) in Florida. Losses were estimated (Phelps and Chellman, 1974) to be $8,000,000 annually. Analysis of rust incidence and distribution in slash pine plantations in North Florida (Schmidt et al., 1974) indicated that the infection rate was increasing each year. Resistance to fusiform rust is present in a small percentage of present slash pine selections (Goddard and Schmidt, 1971; Schmidt and Goddard, 1971); however, due to the genetic variation in the pathogen (Snow, Dinus, and Kais, 1975), and because there is an immediate need for large amounts of resistant material, additional sources must be sought. Recent studies (Goddard et al., 1975) suggest that substantial and immediate gains in rust resistance are possible via rogued seed production plantations in high rust incidence areas.

This paper summarizes additional data from progeny tests of seedlings from a rogued seed production area planted on three high rust hazard sites and provides further evidence that a substantial increase in rust resistance of slash pine can be produced immediately.

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Figure 1.--Approximate locations of the slash pine seed production area for population B (○) and the three high fusiform rust incidence test sites (●).

METHODS AND MATERIALS

Population A consisted of open-pollinated progenies (families) from slash pine selections made in the Cooperative Forest Genetics Research Program at the University of Florida and located in orchards belonging to forest industry cooperators. These selections were made from natural stands within the commercial range of slash pine and include trees from Florida, Georgia, Alabama, Mississippi and South Carolina. Primary emphasis for selection was placed on growth characteristics. Trees with fusiform rust galls were not accepted; however, a few parent selections developed rust galls subsequent to the collection of scion material for orchard establishment. More important, selections were not taken intentionally from areas where rust incidence was high. As such, these selections represent a population having relatively low selection pressure for rust resistance.

Population B consisted of open-pollinated progenies (families) from slash pine selections. These parent selections were the rust-free residuals of a 10-acre "old field" plantation (seed source unknown), in which more than 90% of the original trees had fusiform rust galls. This phenotypically rogued plantation is maintained as a seed production area by Brunswick Pulp Land Company and is located in Wayne County, Ga. (fig. 1). It is isolated among young plantations and presumably receives pollen primarily from within. Progenies (seed collected 3 or more years after roguing) from these selections represent a population having a relatively high selection pressure for fusiform rust resistance.

Seedling progenies were grown in nurseries for approximately one year and outplanted in the winter. Tests were established in Webster County, Ga. in 1971 and 1972 and in Taylor County, Fla. and Bulloch County, Ga. in 1972 (fig. 1) in areas which had very high rust incidence. Seedlings were planted at 2 ft intervals in rows 8 ft apart. Thirty seedlings per family were planted and the design was one ten-tree-row plot randomly located in each of three blocks. The purpose of these plantings was to provide screening for field resistance to fusiform rust. The intention was to establish each family at least once in each location. Due to vagaries of seedling availability, there was variation in replication of families over years and from site to site. The Population A families planted in 1972 were, for the most part, different from the Population A families established the previous year. For Population B in contrast, the majority of the families established in Webster County in 1971 were repeated at the other two locations the following year. There was considerable replication of individual families over the several plantings as indicated in Table 1. For the purpose of this report, families established in each planting are considered as representative of their respective populations.

Table 1.--Location, year planted, and number of families of slash pine established in high fusiform rust incidence areas

Planting location and year	Total number of families established	Number of Common Families in other plantings			
		Webster 1971	Webster 1972	Taylor 1972	Bulloch 1972
		- - - - - - Population A[1/] - - - - - -			
Webster Co., Ga. 1971	146		18	20	27
Webster Co., Ga. 1972	156	18		105	119
Taylor Co., Fla. 1972	126	20	105		103
Bulloch Co., Ga. 1972	156	27	119	103	
		- - - - - - Population B[1/] - - - - - -			
Webster Co., Ga. 1971	147		0	108	110
Webster Co., Ga. 1972	10	0		8	5
Taylor Co., Fla. 1972	117	108	8		114
Bulloch Co., Ga. 1972	117	110	5	114	

[1/] Population A = low selection pressure for rust resistance
Population B = high selection pressure for rust resistance

Data were taken after three seasons of exposure to sporidia of C. fusiforme and were recorded as percent rust per family. This percentage is the number of trees with at least one rust gall expressed as a proportion of the total number of surviving trees in the family.

RESULTS

The average, using family means, percent of trees with rust for population A and B for the three sites are shown in Figure 2. Rust incidence was relatively high for Webster, 1971, 1972, and Taylor County being 75, 62 and 39%, respectively. Average rust incidence on the Bulloch County site was only 11% due to weed competition resulting in poor pine growth (average rust on this site the previous year was 53%). Population B had less rust than population A for all sites: 61, 36, 26 and 6% for population B compared with 85, 63, 47 and 14% for population A on the Webster 1971, 1972; Taylor and Bulloch County sites, respectively.

The relative amount of rust on the two populations is expressed as an infection ratio (average % rust for population B/average % rust for population A) in Figure 3. The infection ratios were 0.72, 0.57, 0.56 and 0.44 for the Webster 1971, 1972; Taylor and Bulloch County sites, respectively, and indicate that population B had approximately 57% as much rust as population A.

Figure 4 shows the frequency distribution of average percent rust by family for population A and B planted in Taylor County. Both populations appear normally distributed with means of 47 and 26% for population A and B, respectively.

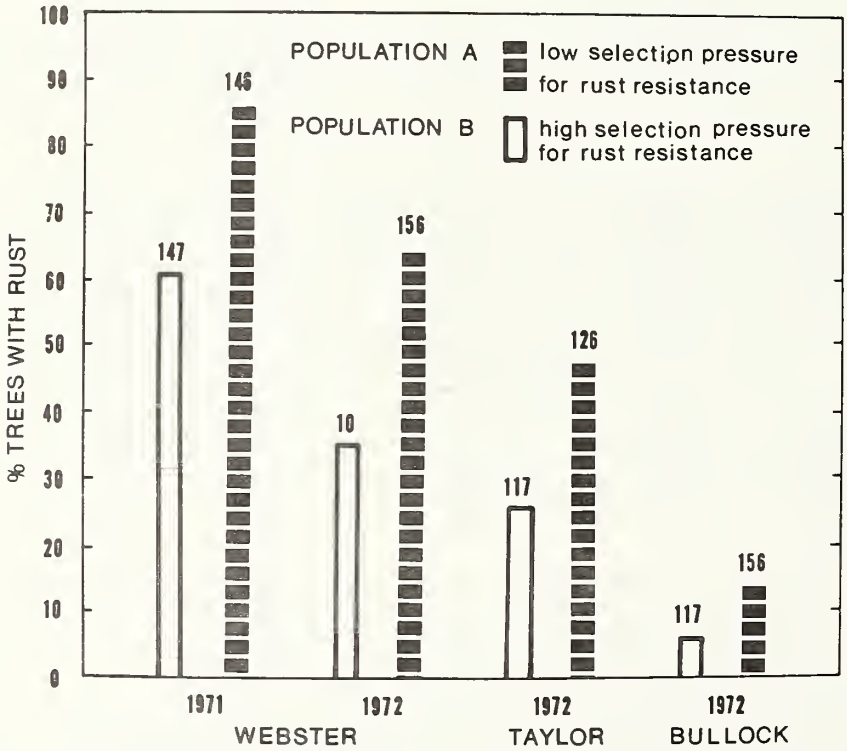

Figure 2.--The average percent of slash pine trees with fusiform rust on three high rust incidence sites. The average was calculated from family means and the number of families is given at the top of each bar.

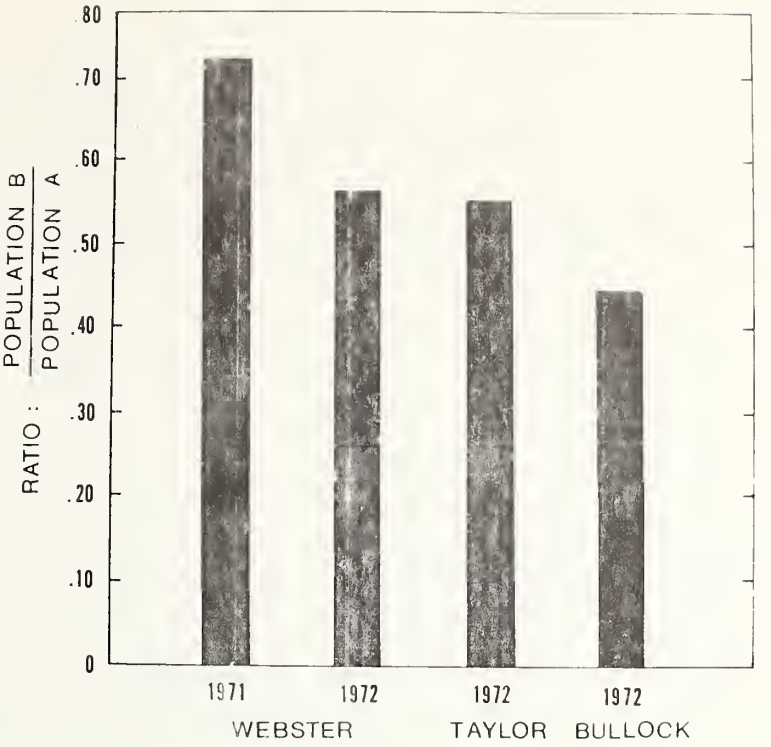

Figure 3.--The ratio (population B/population A) of average percent of slash pine with fusiform rust on three high rust incidence sites. Population A and B represent low and high selection pressure for fusiform rust, respectively.

DISCUSSION

Populations A and B are different regarding relative resistance to C. fusiforme. Although there are some resistant families in population A, most are very susceptible. Numerous field tests (Schmidt and Goddard, 1971) and artificial inoculations (Goddard and Schmidt, 1971) have shown that population A is at least as susceptible as unimproved seed sources.

In contrast, families from population B were relatively resistant. In the parent population, exposure to a high incidence of rust permitted phenotypic identification of resistant trees which were capable of transferring resistance to their progeny. Population B had approximately one-half as much rust as population A which represents nearly 50% gain in the average percent of trees without rust. Gains in fusiform rust have been estimated (Rockwood and Goddard, 1973) at approximately 50% with appropriate breeding programs coupled with progeny tests. The gains reported for population B do not require breeding or progeny testing.

Susceptibility of both populations increased as the level of rust incidence increased. Regarding population B, 34 families were free of rust in the Bulloch County site; only three were rust free in the Taylor County site and no rust-free families were present in the Webster County site. In the Webster County

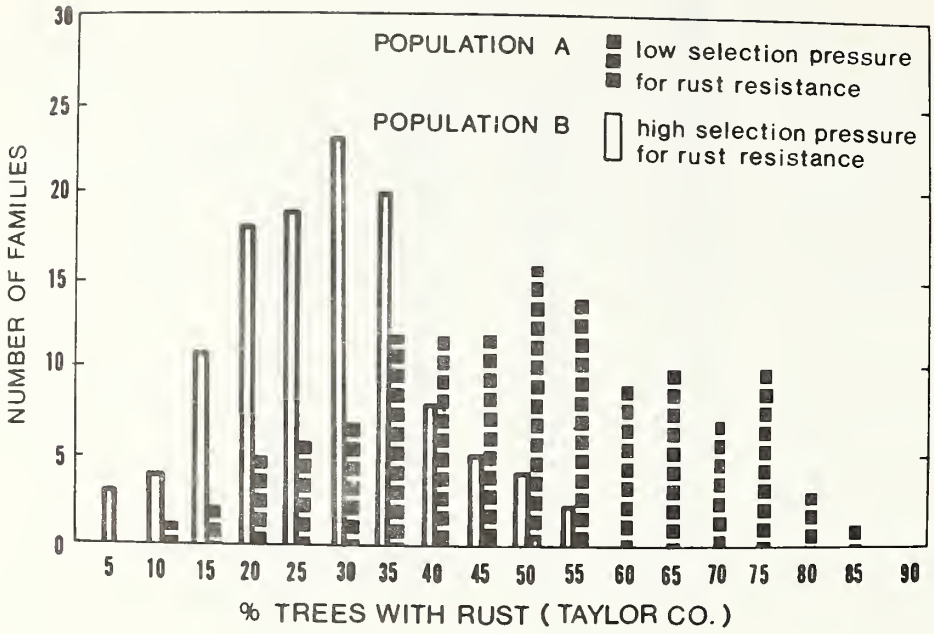

Figure 4.--Frequency distributions of percent trees with fusiform rust for families of slash pine selections representing low (population A) and high (population B) selection pressure for rust resistance and planted in Taylor County, Florida.

site in 1971 (Goddard et al., 1975), there were no rust-free families, in fact, no family had less than 25% of the trees infected. Fortunately, in view of the apparent variability in pathogenicity of C. fusiforme (Snow, Dinus and Kais, 1975), population B exhibited relative resistance on all three sites.

Further evidence for increased susceptibility with increased percentage of disease incidence is provided by a comparison of the frequency distributions for population A in Taylor County (Figure 4) with that previously reported for this population in Webster County (Goddard et al., 1975). At the very high rust incidence (average = 85%) in the previous report, the normal distribution of percent rust by family was no longer evident and was replaced by an exponential distribution as many families approach the limit of 100% susceptibility.

Assuming that the rogued plantation in Wayne County (population B) is not an exception, similar severely diseased plantations, rogued for seed production, can provide rust resistant seed in a relatively short time and at relatively little cost. One added advantage is the saving of genes for rust resistance which would otherwise be lost. Although seed from population B is superior to that of A for rust resistance, it is not suitable for very high rust hazard

areas such as the Webster County site and should probably be confined to areas of moderate rust incidence.

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COMPARATIVE PERFORMANCES OF SLASH PINE FOR FUSIFORM RUST RESISTANCE IN HIGH RUST HAZARD LOCATIONS

S. I. Sohn, R. E. Goddard and R. A. Schmidt[1/]

Abstract.--Rust infection of open-pollinated slash pine families, planted at four sites over two years, differed significantly among geographic origins and families. The year and site differences were even greater. Rank correlations of family infections among sites planted in the same year were good but those between the same sites in different years were poor. Correlation between sites was higher with moderately high infection levels at both sites than when there were large differences in average infection percent. Some families showed consistent rust resistance in all plantings while others were highly variable.

Additional keywords: Pinus elliottii, Cronartium fusiforme, geographic variation.

Southern fusiform rust caused by Cronartium fusiforme Hedge and Hunt ex Cumm. is the most serious disease of slash pine (Pinus elliottii var. elliottii) and there are indications (Schmidt et al., 1973) that the average infection rate is increasing in north Florida and Georgia annually. Thus, rust resistance is a trait of critical importance to genetic improvement of slash pine.

Field resistance is essential in the selection of slash pine clones for inclusion in seed orchards for production of rust resistant planting stock. To provide a broad base of data on relative resistance of clones in the Florida Cooperative Program, four geographically diverse test sites were selected on the basis of high fusiform rust incidence in nearby pine plantations. The four sites are located in Escambia County, Alabama, Taylor County, Florida, Webster County and Bulloch County, Georgia (Fig. 1). Starting in 1971, the plan was to plant progenies of all clones in the Florida Cooperative Program at each location at least one time. Annual plantings have been continued at these locations. In this paper, fusiform rust incidence data of 134 slash pine families from the 1971 and 1972 plantings are reported.

MATERIALS AND METHODS

Open-pollinated progenies of slash pine clones established in each location were planted in ten-tree row plots. Spacing was 0.6 m (2 ft) within rows 2.4 m (8 ft) apart. Randomized plots of each family were planted in each of three blocks per location. The 1972 plantings were adjacent to but not randomized

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within the 1971 plantings. Although more than 300 families were planted in the two years at the four locations, the design is not balanced. Relatively few families were repeated at the same location both years, but a greater number of families was planted at the several locations during a single year.

Rust infection was assessed in January, 1974 and January, 1975, three years after planting in each case except for the Escambia County, Alabama, site. Because of low infection rates at this site, data for the 1971 planting were recorded after four years and the 1972 planting was not examined in detail. Data were recorded as percent rust per plot. This percentage was based on the number of trees with at least one rust gall expressed as a proportion of the total number of surviving trees in the plot.

Data analysis.--Although the primary objective of these plantings was to determine relative rust resistance of individual families, geographic origins of many parental ortets could be grouped into seven rather discrete areas (Fig. 1). For geographic locations (two or more adjacent counties) represented by five or more families, least squares analysis of variance was computed to partition the effect of geographic origin. Families from the several areas were assumed representative of the native slash pine population of the area in relative resistance to fusiform rust. Effects of the planting locations, year of establishment and several interaction terms were also tested by the least squares analysis of variance method.

Determination of the interactions of families with planting locations and year were accomplished by three separate analyses. The four locations planted in 1971 were compared on the basis of data from sixty-six families commonly represented at all sites. A second group of fifty-four families was used for comparison of three locations planted in 1972. Finally, a separate analysis was run with fourteen families planted at all locations both years. To indicate consistency of relative infection levels of families included in the various analyses, or conversely, the degree of family x environmental interaction, rank correlation tests were applied for each group based on the average infection value of the families at each location and year.

RESULTS

Rust infection differed significantly among the geographic origins represented as well as among families within geographic origin (Table 1). Families from the vicinity of Emanuel County, Georgia and Taylor County, Florida, tended to have the least infection. Families from Baker and St. Johns County, Florida, tended to have the most infection (Table 2).

Infection rates were highly variable among planting locations and years (Fig. 2). However, for most plantings the frequency of families by infection classes appear to fit a normal distribution pattern (Fig. 3). The exceptions were with very high average infection in the 1971 Webster County planting and the low infection at Bulloch County in the 1972 planting.

Significant interactions were observed for geographic origin x planting location, and particularly for family within origin x location for each establishment year. However, rank correlation analyses of family infections in all possible sets of two locations within a given year were significant

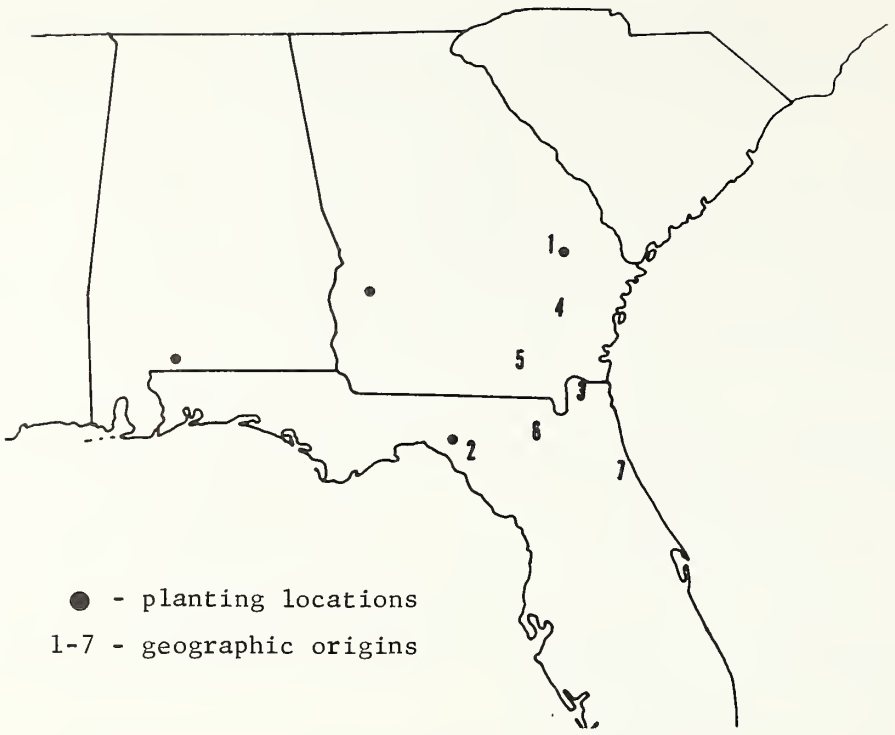

Figure 1.--Location of four planting sites and seven geographic origins.

Table 1.--Least square analysis of variance of rust infection in open-pollinated slash pine families.

Sources	d.f.	M.S.
Year (Y)	1	32230**
Location (Year) (L/Y)	5	130700**
Seed Source (S)	6	6220**
Y x S	6	669
S x L/Y	30	354*
Family (Source) (F/S)	118	1558**
Y x F/S	117	1317**
F/S x L/Y	316	298*
Error	874	193
Total	1473	

* Significant at the 0.05 level
** Significant at the 0.01 level

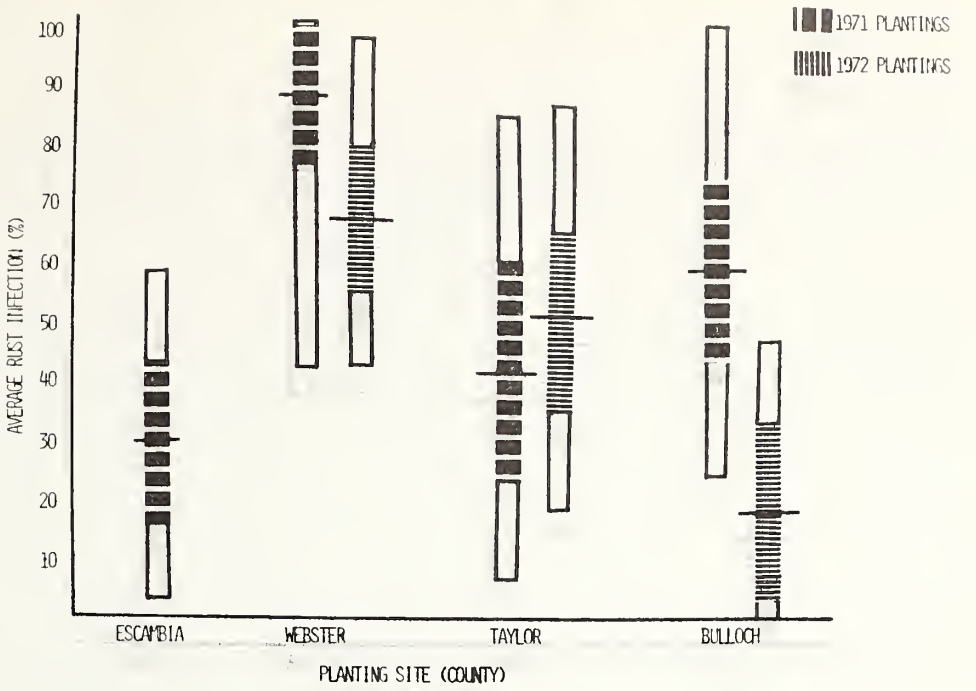

Figure 2.--Effect of planting locations and year of planting on fusiform rust in slash pine (range, mean and standard deviation).

Table 2.--Average percent fusiform rust on slash pine families from different geographic origins planted in high rust hazard locations.

Geographic origin	Average infection (%) 1/	Number of families
Emanuel-Laurens-Tattnall, Ga.	36.9	6
Taylor-Dixie-Lafayette, Fla.	41.9	41
Camden, Ga.-Nassau, Fla.	50.3	33
Long-Wayne-Appling-Dodge, Ga.	50.9	9
Ware-Clinch, Ga.	51.4	6
Baker-Clay-Union-Columbia, Fla.	55.4	25
St. Johns-Flagler, Fla.	55.7	14

1/ Average infection percents not within the same bracket are significantly different at the 0.05 level.

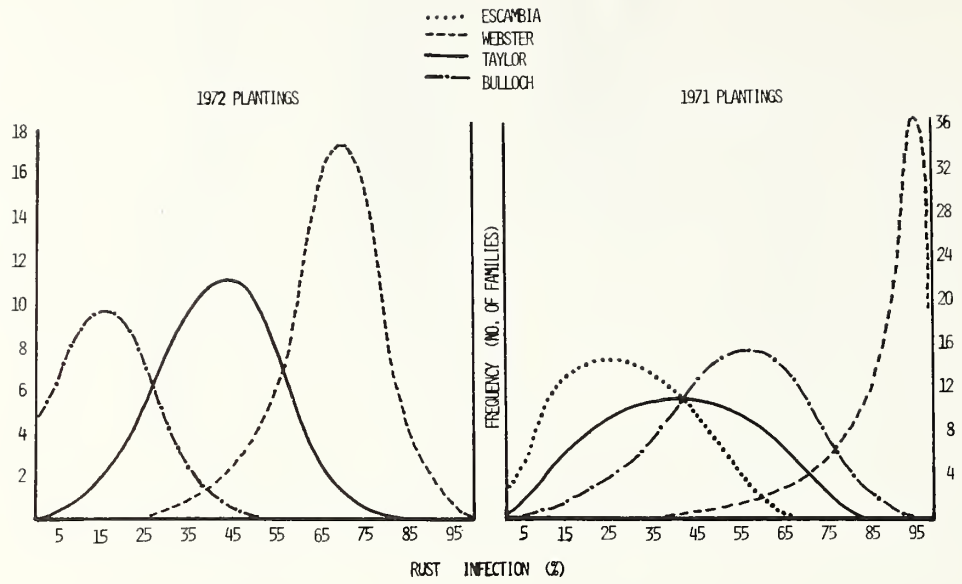

Figure 3.--Frequency distribution of percent fusiform rust on families of slash pine planted in high rust hazard locations in 1971 and 1972.

Table 3.--Rank correlation coefficients (R) of the average rust infection of open-pollinated slash pine families between locations within planting years.

1971 plantings N = 66	r[1/]
Escambia vs. Webster	0.46
Escambia vs. Taylor	0.56
Escambia vs. Bulloch	0.45
Webster vs. Taylor	0.30
Webster vs. Bulloch	0.46
Taylor vs. Bulloch	0.44
1972 plantings N = 54	
Webster vs. Taylor	0.53
Webster vs. Bulloch	0.52
Bulloch vs. Taylor	0.48

[1/] Correlation coefficients are significant at the 0.01 level when higher than 0.32 with 64 degrees of freedom or 0.35 with 52 degrees of freedom.

(Table 3). Fourteen families planted in all locations both years had poor year to year correlations in the Webster and Bulloch County plantings, while correlation between years at the Taylor County site was significant statistically (Table 4).

DISCUSSION

Geographic origin had an evident effect on resistance to C. fusiforme in open-pollinated slash pine families. Strong seed source effects on rust infection in loblolly pine (Wells and Wakeley, 1966) and in slash pine (Gansel et al., 1972) have been reported. Two geographic origins, Emanuel County, Georgia, and Taylor County, Florida, which showed the lowest infection rate were reported as areas of high rust incidence (Phelps, 1974). In loblolly pine, trees from the provenances of the least infection showed also the least infection. But in slash pine, trees from the geographic areas of the relatively high infection showed the least infection in this study. Goddard et al. (1975) have shown that phenotypic selection of rust-free trees from areas of high rust incidence can provide significant gains in rust resistance of slash pine. The effect of seed source per se, however, does not appear to be as pronounced in slash pine as it is in loblolly pine.

For reliable differentiation of families for rust resistance, moderately heavy infection levels are required. With extremely high infection levels (Webster County, 1971), resistance mechanisms appear to be overcome. In very low infection rates (Bulloch County, 1972), distribution of infection was rather random (Schmidt and Goddard, 1971). Poor correlations of Bulloch County, 1972 planting with three locations in 1971 plantings would be good examples. In the middle range of mean infection level, frequency distribution of rust incidence appears normal and good differentiation of rust resistant families was possible.

Many of the families showed consistent rankings over all locations, while some changed their rankings rather drastically in one location (Table 5). Family 49-61 was ranked as one of the resistant group in three locations but as susceptible in Webster County, 1971 planting. Behavior of these families supports the reports of the pathogenic variability in C. fusiforme (Snow et al., 1972, 1975). This can be also evidence for the possible presence of the vertical resistance to fusiform rust in some slash pines along with the horizontal resistance in other families (i.e. family 316-56).

At least over the three year period of these tests, year to year variation was very high. Rockwood and Goddard (1973) also observed a strong year effect in slash pine. The expectation that open-pollinated families replicated in successive years in the same location would be infected at a relatively consistent level was not substantiated. Correlations between two years in Webster County and Bulloch County were not significant statistically. The high correlation in Taylor County seems to be due to moderately heavy and similar infection levels in both years. Significant correlation between the Bulloch County in 1971 planting and the Taylor County 1972 planting also suggests that moderately heavy infection levels are required for good correlation between years as well as sites. The fourteen families included in plantings at all sites both years however, provide a limited basis for this conclusion.

Table 4.--Rank correlation coefficient (R) of the average rust infection of open-pollinated slash pine families between two years and three locations.

N = 14

	Average Infection level (%)	1971		
		Webster (79%)	Taylor (31%)	Bulloch (43%)
1972	Webster (59%)	0.44	0.39	0.45
	Taylor (46%)	0.41	0.70*	0.66*
	Bulloch (8%)	-0.06	0.18	0.24

* Correlation coefficients 0.66 or higher are significant at the 0.01 level.

Table 5.--Relative resistance of open-pollinated families to fusiform rust in four locations (from 1971 plantings).

Families	Locations			
	Escambia	Webster	Taylor	Bulloch
	- - - relative resistance class[1/] - - -			
49-61	1	5	1	1
316-56	1	1	1	1
262-55	5	1	3	3
191-57	1	1	1	4
296-56	1	4	3	5
94-56	5	5	5	5

[1/] 1 : Resistant (upper 20% in ranking)
2 : Fairly resistant (next 15% in ranking)
3 : Medium (next 30% in ranking)
4 : Fairly susceptible (next 15% in ranking)
5 : Susceptible (next 20% in ranking)

Procedures for testing should be revised to include replication over time as well as over planting sites.

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IMPACT OF FUSIFORM RUST (*CRONARTIUM FUSIFORME* HEDGC & HUNT EX CUMM.) INFECTION IN PLANTATIONS OF LOBLOLLY AND SLASH PINES ON A HIGH-HAZARD SITE IN GEORGIA

Earl R. Sluder

Abstract.--In two progeny test plantations 69 percent of the loblolly pine and 64 percent of the slash pine seedlings were infected with fusiform rust at age 3. Per-acre volume loss at age 15 resulting from a combination of rust-caused mortality, reduced growth in infected stems, and unusable or low-value canker tissue amounted to 60 percent in the loblolly and 56 percent in the slash compared with volume expected in the absence of rust. Progenies showed wide variation in susceptibility to infection and subsequent mortality by the rust.

Additional keywords: variation, progeny tests, *Pinus elliottii*, *P. taeda*.

(The complete text of this paper has been submitted for publication in Forest Science.)

SESSION V - GENERAL

MODERATOR: ROBERT G. HITT

GENOTYPIC STABILITY COMPARISONS IN LOBLOLLY PINE

Fredrick Owino [1/]

Abstract.--Phenotypic regressions with coefficients of about 1.2 were calculated for height growth four years after planting loblolly pine in nine diverse locations in five southeastern states. The heterogeneity of the coefficients of all 18 sets of families was shown to be statistically nonsignificant and therefore that wide-cross, local-cross, and open-pollinated progeny do not differ in stability.

Additional keywords: Adaptation analysis, Pinus taeda

Wide adaptability is a highly desirable character for the breeding genotypes to possess for most tree breeding objectives. A technique for assessing genotypic stability, first described by Finlay and Wilkinson (1963), consists of growing a number of genotypes in a number of environments, quantifying the environmental quality by the average expression of all the genotypes at the particular environments and then estimating the linear regression of the value of each genotype on the mean values for the environments. According to this technique, a perfectly stable genotype (b=0) is completely unresponsive to changing environments. Such genotypes are undesirable in most tree breeding situations because they cannot take advantage of silvicultural improvements. A genotype of average genotypic stability (b=1) shows added performance in the better environments in proportion to the added improvement in environmental quality. A genotype with b>1 will perform better than average in the better environments but less than average in the poor environments. Conversely, a genotype with b<1 will perform better than average in the poor environments but less than average on the better environments. Selecting for genotypes with appropriate stabilities for specific breeding objectives can therefore result in increased yields. The investigations reported here were aimed at comparing genotypic stabilities of intra- and interregional crosses of loblolly pine.

METHODS

The crosses on which the study is based were made by Dr. R. Woessner in 1964 and 1965. Four seed orchard trees indigenous to the North Carolina Piedmont (Hoerner-Waldorf seed orchard) and four seed orchard trees indigenous to the North Carolina Coastal Plain (Weyerhaeuser seed orchard) were crossed with pollen of seed orchard trees from ten widely separated geographic areas. Also, open-pollinated seed of 32 pollen and seed parents were included in the study.

The seedlings were outplanted at twelve locations in five southeastern states in spring 1968. Randomized complete-block design with 10-tree row plots planted at 9' x 9' spacing was used at all locations assessed except for the planting in Tyrrell County which had 2-tree row plots.

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RESULTS

Of the four characters assessed (height growth, fusiform rust score, crown score, and stem straightness), it was found that height growth is most sensitive to environmental changes. Height growth of trees on the best site was over twice that of those on the poorest site. Such large differences would be expected because the test locations were purposely chosen to sample extreme environments as well as intermediate ones. There were also great differences in the degree of rust infection from location to location, but such variability was indifferent to site quality.

Table 1. Mean height growth of single crosses of loblolly pine grown in six locations

	Locations[1/]					
Crosses	1	2	3	4	5	7
6-9 x 10-37	19.56	12.71	13.74	12.09	12.44	10.66
6-9 x 11-504	18.39	13.47	12.48	12.97	11.74	11.22
8-33 x 11-30	17.35	11.60	10.19	9.64	10.14	8.31
6-9 x GRI-2	-	12.74	-	10.48	10.70	10.90
Commercial Check	-	11.16	-	10.52	10.75	9.56
6-9 x 11-9	19.26	13.24	-	-	-	14.08
6-20 x 1-9	-	-	9.62	10.47	-	8.05
6-7 x 8-30	17.00	-	-	-	11.89	8.25
Average	17.65	12.06	11.39	11.11	10.61	9.85

[1/] Legend for Table 1

Location	County	State	Company
1	Jackson	La.	Continental Can
2	Shelby	Ala.	Kimberly-Clark
3	Bullock	Ga.	Continental Can
4	Rhea	Tenn.	Bowaters
5	Halifax	N. C.	Hoerner-Waldorf
7	Murray	Ga.	Bowaters

Table 2. Mean rust scores for single crosses at four locations in the Southeast

	Location (County and State)			
Crosses	Jackson, La.	Bullock, Ga.	Columbus, N. C.	Kershaw, S. C.
6-9 x H-2	3.46	1.90	1.71	1.65
8-33 x GRI-12	1.46	1.18	1.00	1.05
8-68 x GRI-16	1.03	1.28	1.21	1.15
6-20 x 11-510	3.79	2.30	2.77	2.43
Average	2.54	1.49	1.56	1.49

It was evident that single crosses tend to retain the same relative ranks from location to location--an indication that genotype x environment interaction may not be very important (Tables 1 and 2). The performances of three sets of families were shown to be linearly related to the environmental quality (Figure 1). These three sets of families were chosen to represent open-pollinated progeny, local crosses, and wide crosses. A general analysis for eighteen sets of open-pollinated progeny, local and wide crosses resulted in a rather homogenous set of regression coefficients with average value of about 1.20 (Table 3).

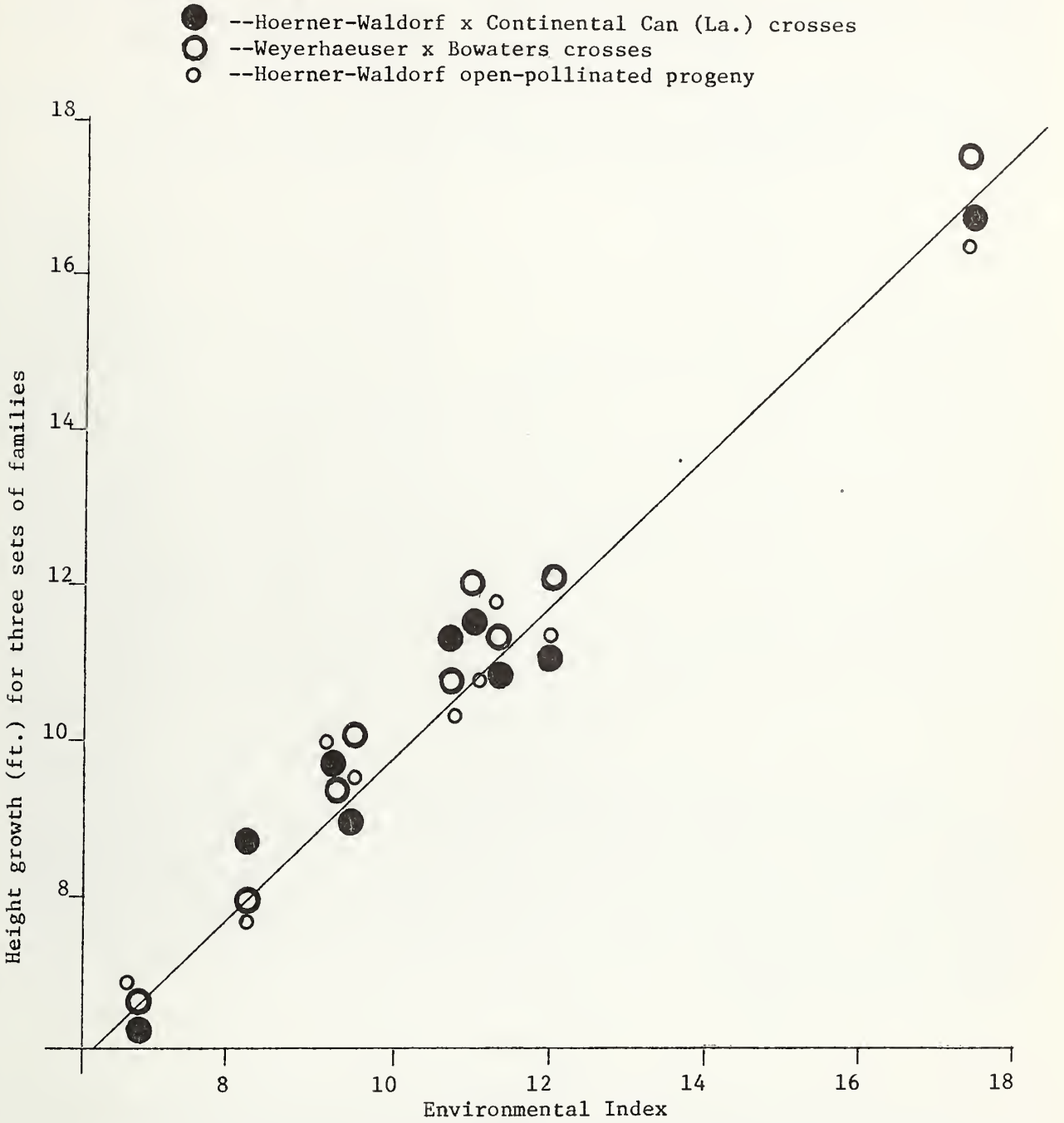

Figure 1. Graphical presentation of the relationship between family means and environmental index (mean of all genotypes at the particular environment)

Table 3. Mean height over all locations for family groups and genotypic stabilities calculated by the regression coefficient (Finlay and Wilkinson, 1963)

Family	Mean Height (ft.)	Regression Coefficient
Commercial check	10.26	1.244
Westvaco O.P.	10.12	1.302
Weyerhaeuser O.P.	10.46	1.230
Hoerner-Waldorf O.P.	10.38	1.134
Weyerhaeuser x Weyerhaeuser	10.53	1.290
Hoerner-Waldorf x Hoerner-Waldorf	10.71	1.122
Hoerner-Waldorf x Weyerhaeuser	10.19	1.226
Hoerner-Waldorf x Union Camp	10.53	1.204
Hoerner-Waldorf x Kimberly-Clark	10.29	1.302
Hoerner-Waldorf x Westvaco	10.82	1.234
Hoerner-Waldorf x Continental Can (East)	10.11	1.073
Weyerhaeuser x Bowaters	10.90	1.283
Weyerhaeuser x Continental Can (La.)	10.34	1.201
Weyerhaeuser x Champion	10.32	1.214
Weyerhaeuser x Continental Can (East)	10.06	1.179
Weyerhaeuser x Texas	10.52	1.352
Hoerner-Waldorf x Texas	10.81	1.285
Hoerner-Waldorf x Continental Can (La.)	10.56	1.374

DISCUSSION

Judged by the regression coefficients, all 18 sets of families show genotypic stabilities well below the average stability of b=1.0, with the only exception being the Hoerner-Waldorf x Continental Can (East) set of crosses (Table 3). Such a trend indicates that forest productivity can be increased by using the best genetic stock coupled with optimal cultural practice, as compared to the contribution from genetic improvement and silvicultural improvements singly. The response observed also implies that a disparity can be expected between predicted and realized gain when the progeny are raised in the better environments.

CONCLUSIONS

These stability analyses have shown that the selected loblolly pine families have below average genotypic stabilities and therefore that they are better adapted to the more favorable environments. This adds justification

for improved plantation practices, including intensive site preparation and fertilization. These and other analyses (Owino, 1975) also show that the different sets of families do not differ much in their stabilities, indicating that stability assessment should play only a secondary role in plus-tree selection.

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RESPONSE OF A YELLOW-POPLAR SWAMP ECOTYPE TO SOIL MOISTURE

Richard C. Schultz and Paul P. Kormanik[1/]

Abstract. Pot testing of yellow-poplar may be a rapid method of identifying the variability of progeny from mature trees. One-year-old seedlings of a swamp ecotype of yellow-poplar (Liriodendron tulipifera L.) were grown in 37-liter cans under gravimetrically controlled soil moisture tensions for 7 weeks. Dry matter production of roots, stems and leaves increased as soil moisture increased. Root/shoot ratio did not vary. The number of leaves per seedling increased fourfold as soil moisture tension decreased from 15 atm to saturation. Differences between the diameters of the root collar and 30 cm above the root collar increased as soil moisture increased. Height growth during the 7 weeks of treatment increased as moisture increased. Seedlings grown under near saturated conditions lost their leaves 11 days after water was withheld. Seedlings grown at 0.1 and 15 atm retained their leaves 45 and 70 days respectively after water was withheld.

Additional keywords: Dry matter production, plant water potential, Liriodendron tulipifera L.

Large-scale progeny tests to assess the growth potential of hardwoods are time-consuming, difficult and expensive (Farmer et al. 1967, Kellison 1970, and Thor 1975). Attempts to assess variations in performance in different environments in field progeny tests greatly increase the costs. To overcome these limitations of progeny testing, we initiated a yellow-poplar (Liriodendron tulipifera L.) selection and testing program in 1970 which uses vegetative propagules of selected trees under defined environmental stresses. We feel that ramets grown under specified induced stresses, in large containers, can be used to estimate performance in different environments in relatively short studies. This procedure would save both money and time in field progeny tests.

The problem, of course, is to design a pot study whose results are truly indicative of long-term field performance. If we can do so, progeny from selected trees can be given this brief test before they are introduced into seed orchards. The relationship between moisture stress in the plant and soil will be a key variable. In previous tests we observed responses of upland yellow-poplars to various soil moisture regimes (Kormanik and Schultz, 1975). In the study described here we observed responses to moisture stress by the coastal plain ecotype of yellow-poplar described by Kellison (1970). Thus, we have now observed the full range in yellow-poplar responses and are prepared to specify some of the conditions for our pot tests.

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Soil moisture was selected for the test because of both the site requirements of this swamp ecotype (Kellison, 1970) and our continuing interest in identifying different hardwood clonal lines which perform well on a broad range of site conditions.

The soil moisture tensions were gravimetrically induced in pot soil mixtures. Although it is not possible to continuously maintain a given soil moisture tension in a potted soil mixture, we feel that growing seedlings under drying cycles to specific levels of soil moisture tensions before rewatering approximate the conditions found on natural sites.

METHODS

Yellow-poplar swamp ecotype seedlings were planted in 37-liter cans filled with a 1:1:1 mixture of a forest loam, sand and peat. The 1-0 seedlings had been grown from a mixed seedlot collected in the Dismal Swamp of Virginia.[2/] Large cans were used to provide sufficient rooting medium for root growth comparisons. The seedlings were planted in April and allowed 2½ months to become established. During this time all pots were regularly watered and fertilized.

A soil moisture tension curve was developed for the soil mixture (Richards, 1965). Because of the site adaptability of the swamp ecotype soil moisture treatments were assigned at 15 and 0.1 atmospheres and near pot saturation. The levels corresponded to moisture contents of 3, 14 and 30 percent ovendry soil weight for the dry, moist and wet treatments. Moisture levels were gravimetrically controlled by allowing the soil to dry to the prescribed moisture level and resaturating it. The large pots minimized the need for frequent rewatering, thus subjecting seedlings to long periods of developing stress. As the study was carried out in a lathe house, all pots were covered with styrofoam to exclude rain.

Moisture treatments were started in July and continued for 7 weeks. The graded seedlings were randomly assigned a moisture treatment and each treatment was replicated seven times. Each pot was randomly assigned a position in the lathe house. During the treatment period, saturated pots of the wet treatment were watered daily. The pots at the moist and dry treatments were watered approximately every 5 and 20 to 30 days, respectively. During the treatment period heights were measured weekly and all dead leaves were collected from each seedling and dried.

The day before harvesting, water potentials of trees at their maximum prescribed soil moisture treatment tensions were monitored by the pressure-bomb method (Scholander et al., 1965). Leaf water potentials were measured every two hours over a 16 hour period starting at 7 a.m. and ending 11 p.m. Both the day prior to and the day of monitoring were clear, warm and dry with temperatures around 26° C and relative humidities between 50 and 60 percent.

On the day of harvest, seedlings from five replications were removed from the pots, root collar diameter, diameter 30 cm above the root collar, total height

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[2/] Seeds were collected by Robert D. Heeren, Project Leader, Hardwood Silviculture Management, Union Camp Corporation, Franklin, Virginia.

and number of leaves per seedling were measured. Dry weights of all seedling parts were obtained by drying the plant material at 72° C to constant weight.

Two of the seven replications of seedlings were allowed to dry until their leaves began to drop. Soil in these pots was saturated the day after water potential monitoring and the seedlings were harvested at the end of their leaf drop period.

Differences between treatment means for the measured growth variables were tested by analysis of variance and Duncan's Multiple Range Test (Steele and Torrie, 1960).

RESULTS AND DISCUSSION

Significant differences in the dry weights of the roots, stems and leaves were found between seedlings grown for only 7 weeks at the different moisture levels (Figure 1, Table 1). Total and root weights of the seedlings grown at the wet moisture level were four times greater than those of seedlings grown at the dry treatment. Total leaf weight over the same range showed a tenfold difference while the root/shoot ratio of the seedlings showed no significant differences. These data generally agree with those reported elsewhere (Pope and Madgwick, 1974, Kormanik and Schultz, 1975). Root weights of this swamp ecotype decreased as the soil became drier. Progeny of trees exhibiting this response probably would not be suitable for planting over a wide variety of sites. The ability to produce consistently large root systems over broad ranges of soil moisture conditions is an attribute required of seedlings used in broad scale planting programs. In a previous study, consistently large root systems were produced by clonal material selected from dry upland sites and typical yellow-poplar cove sites and grown in pots over a similar soil moisture range (Kormanik and Schultz 1975). In one upland and one cove clone, oven-dry root weights varied less than 6 grams between ramets grown under drying cycles of 1 atm and 15 atm of soil moisture tension. In three other clones ovendry root weights varied over 52 grams over the same soil moisture range. The swamp ecotype showed a 75 gram difference in ovendry root weights between seedlings grown at saturation and 15 atm of soil moisture tension. This ecotype is very sensitive to changes in soil moisture conditions. The large difference in root production response of these genetically different yellow-poplar strains suggests that root mass production ability under varying soil moisture regimes is an excellent selection criteria.

The large differences in leaf weight were the result of both new growth and senescence of old leaves. During the first dry-down cycle seedlings subjected to the dry treatment lost many of their large lower leaves. These leaves were subsequently replaced by fewer and generally smaller ones. The dry weights of the fallen leaves are reflected in the leaf weight for each treatment. The difference in the number of leaves per seedling showed large increases not only between the dry and moist treatment levels but also between the moist and wet levels (Table 2). This large increase in leaf number suggests again that this ecotype of yellow-poplar is very sensitive to soil moisture stress.

Table 1.--Means of yellow-poplar swamp ecotype growth variables for seedlings grown at soil moisture levels of 3, 14 and 30% ovendry weight

Soil Moisture Level %	Dry weights (grams)				Root/Shoot Ratio
	Total	Root	Stem	Leaf	
3 (dry)	60.0	24.1	29.4	6.5	0.65
14 (moist)	188.3	77.6	71.1	39.6	0.70
30 (wet)	240.5	98.8	81.9	59.8	0.71

Means grouped by lines are not significantly different at the 5% level. All other means are significantly different from one another at least at the 5% level.

In an attempt to identify whether the swamp ecotype responded to wet sites by increased butt swelling, the diameters at the root collar and 30 cm above the root collar were compared. As can be seen in Table 2 the difference between the two measures did vary significantly between the dry and moist soil moisture levels. Although no anatomical analyses were attempted the data would suggest that this swamp ecotype has a tendency to develop butt swell as is common to swamp species.

Height growth in the seven week period also varied between the dry and moist treatment levels but showed little change between the moist and wet levels (Table 2).

Table 2.--Means of yellow-poplar swamp ecotype growth variables grown at soil moisture levels of 3, 14 and 30% ovendry weight

Soil Moisture Level %	Number of Leaves per Seedling	Root collar diameter cm	Diameter 30 cm above root collar	Difference in diameter cm	Height growth in 7 wks. cm
3 (dry)	36	1.84	1.21	0.63	17.2
14 (moist)	95	2.59	1.48	1.11	32.8
30 (wet)	153	2.79	1.59	1.20	37.6

Means grouped by lines are not significantly different at the 5% level. All other means are significantly different from one another at least at the 5% level.

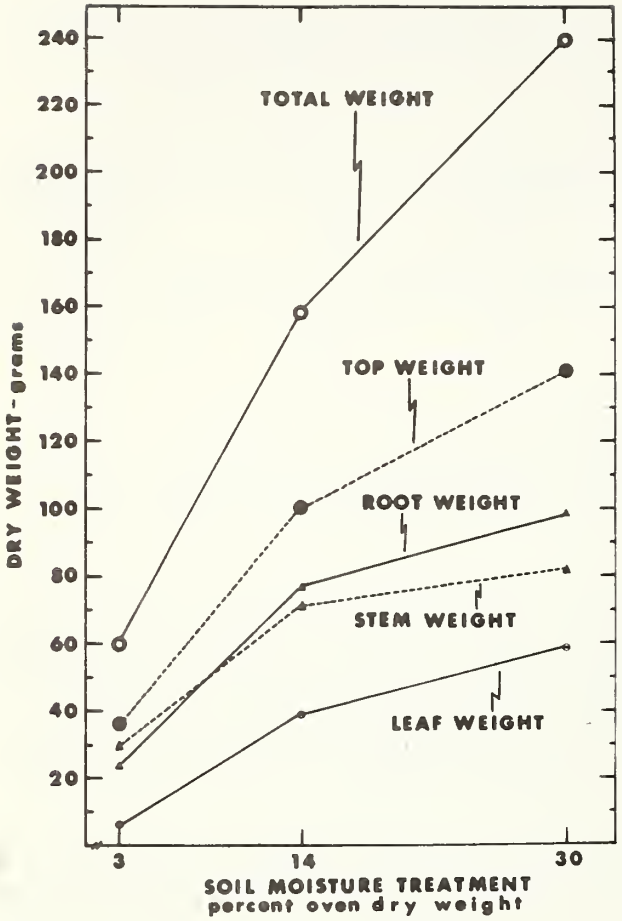

Fig. 1--Mean dry weights of yellow poplar seedlings grown at 3 soil moisture levels.

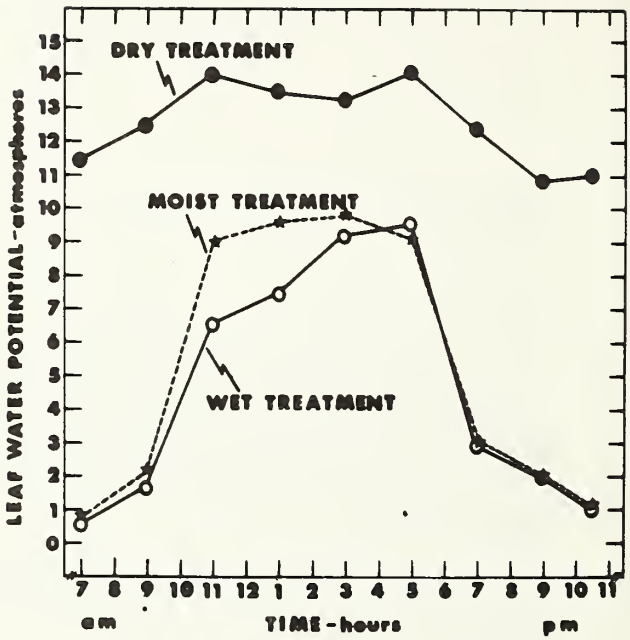

Fig. 2--Mean leaf water potentials for seedlings of yellow-poplar grown at 3 soil moisture levels.

The results of the internal moisture stress measurements (Figure 2) clearly show the direct effect of soil moisture deficit on the water status in the seedlings. Both the wet and moist treatments showed the daily transpirational lag which is responsible for midday moisture deficits. From Figure 2, the effect of available water on the transpirational lag can be clearly seen in the dry treatment. At the 3% soil moisture level the low available water resulted in almost no midday deficit, suggesting that these seedlings were growing near the threshold of permanent wilting. Thus, as these tensions developed in the dry-down cycle of the dry treatment, growth of the seedlings was severely curtailed. The relationship of a small root system and the high leaf-water potentials of trees grown under stress seem closely correlated. Seedlings with small root systems showed poor growth because they developed high leaf-water potentials during the day and were unable to regain sufficient turgor during the night.

Although not tested, it is assumed that the previously described dry upland clonal selections, with the consistently large root systems would have shown less leaf-moisture stress under the low soil moisture treatments. An extensive field comparison of leaf-water potentials outplanted swamp ecotype seedlings and dry site upland seedlings is presently under way. It may well be that the most direct method for comparing site adaptability is to compare leaf-water potentials of selected genotypes grown under controlled soil moisture conditions.

At the end of the investigation described above, two seedlings from each treatment were watered to saturation, set aside, and no further watering given them. Leaves on those trees grown previously under the wet treatment (daily watering) began to brown by the 8th day. By the 11th day, most of the leaves on these trees had died and the apical buds showed signs of desiccation. In contrast, those seedlings previously grown for seven weeks under both the moist and dry treatments showed little browning of leaves until 45 and 70 days, respectively. The trees at these two levels had previously lost their succulent leaves when the watering treatments were first initiated. Apparently, the leaves formed while growing under treatment stress were tolerant of renewed drying cycles as evidenced by the fact that these leaves were not shed during the duration of the investigation. Although these smaller, later developed leaves were tolerant to moisture stress, growth of these seedlings was significantly reduced.

The response of the swamp ecotype in this experiment and results from previous studies indicates that yellow-poplar genotypes can perform over a broad range of soil moisture site conditions. The moisture status of the soil and plant are one of the most critical limiting factors in seedling survival and tree growth. Thus selections for growth responses to soil moisture should be made. We feel that pot testing can provide a quick test of this adaptability.

For successful use of the pot testing method, the technique must be adapted to the species being tested. Earlier trials with smaller pots and thus limited soil volume led to some root binding with yellow-poplar. The more frequent watering of these smaller pots led to increased leaching and some nutrient deficiencies. With a fast growing species such as yellow-poplar, a pot size of at least 30 liters is necessary. This provides both the larger soil volume needed for accurate root mass comparisons and the longer drying cycles needed for extended stress on growth processes. At least three levels of treatment from soil saturation to 15 atmospheres of tension should be used in soil moisture tests. At present we feel that comparisons of ovendry weight of leaves, stems and roots are necessary to identify the distribution of biomass between selections. We also feel that a measure of internal water potential at critical stages in the drying cycle will provide a non-destructive selection parameter.

Pot testing can be used as an early selection method for identifying specific site adaptability between selections. It could be used not only for controlled soil moisture tests but for soil composition, fertility, temperature and other environmental factor tests. This pot pretesting could aid in providing early selection data for use in tree improvement programs.

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GIRDLING PROMOTES ROOTING OF SLASH PINE CUTTINGS

Robert C. Hare[1/]

Abstract.--When cuttings from 12-year-old slash pines were taken 2 months after girdling and chemical treatment of branches in late July, 34 percent rooted in 3 months; but only 1 percent of the ungirdled cuttings rooted. Survival figures were 66 percent and 7 percent, respectively. Poor rooting and survival of control cuttings is ascribed to low food reserves leading to needle-base senescence and death. The girdling and chemical treatment presumably forces accumulation of food reserves and precallusing. Girdled cuttings with preformed root initials generally developed large root systems within a month.

Additional keywords: Vegetative propagation, growth substances, Pinus elliottii var. elliottii.

Many forest trees are being propagated from improved seed produced in clonal seed orchards. Grafting is used almost exclusively to establish the orchards because cuttings from trees old enough to show desirable traits are extremely difficult to root. An improved ability to root cuttings from both first and second generation select trees would enable tree improvement workers to achieve more rapid genetic gains. Other applications for rooting include building up clones for research purposes, compatible rootstock production, and clonal reforestation.

In an optimal environment, the principal limiting factors in pine rooting are growth substances to induce root initiation, food reserves for root growth and shoot metabolism, and fungal decay. A rooting powder (Hare 1974) supplies the needed growth substances, sucrose, and a fungicide. However, shoots from older trees have little storage tissue, and they cannot accumulate sufficient food reserves in the propagating bed because, as Cameron and Rook (1974) have shown, detached cuttings have a low rate of photosynthesis. When addditional CO_2 was provided to enhance photosynthesis, cuttings from 12- and 13-year-old pines rooted well in a growth chamber (Hare 1974). Since chamber operation is too costly for a large-scale production program, van Buitjenen et al. (1975) adapted the above techniques to a greenhouse, using plastic enclosures to contain the CO_2. However temperature buildup is a problem in summer, and CO_2 is expensive.

In the present study, greenhouse rooting of cuttings from 12-year-old slash pine (Pinus elliottii var. elliottii Englem.) was improved by girdling branches and applying chemicals to enhance accumulation of carbohydrate reserves and induce precallusing. This treatment was first reported by Thulin and Faulds (1968) on radiata pine (P. radiata D. Don.).

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MATERIALS AND METHODS

Cuttings were obtained from 96 vigorous trees in a slash pine provenance trial which had been planted in southern Mississippi in 1962 as single-tree plots from widely scattered sources throughout the South. Ortets were selected at random as to seed source. On each of two dates, July 30 and October 24, 1974, four shoots were tagged per ortet, two for girdling and two for controls. Shoots were chosen to provide 15-cm cuttings that were generally less than 1 year old but had some mature needles. Girdling was done by removing a 2-cm ring of bark 15 cm below the terminal bud, after which the distal portion of the wound was covered with a water paste of 1-1-10-10-1 rooting powder (see Appendix). The girdle was then wrapped with saran film and aluminum foil. Two months later these shoots were severed at the distal end of the girdle. Control cuttings were cut 15 cm below their tip. All cuttings were placed in polyethylene bags for transport to the greenhouse. Cutting bases were moistened, dipped in the rooting powder, and inserted 5 cm deep in perlite-vermiculite medium. To avoid possible inhibition of root growth by auxin, girdled cuttings with preformed root initials were treated with 10 percent sucrose and captan in talc instead of the regular powder. Spacing was 10 by 10 cm, intermittent mist was controlled by evaporation from a screen, and bottom heating provided 27°C in the medium. Minimum air temperature was 16°C, and summer cooling was provided by a fan-and-pad system.

A split-plot design was repeated over two beds, each in a different greenhouse. Each bed had six blocks containing two plots, one girdled and one ungirdled; there were 16 cuttings per plot. Survival and rooting data were taken after 1, 2, and 3 months and expressed on a plot basis. Proportions were transformed to arc sine $\sqrt{\text{proportion}}$ for analysis of variance. All tests of significance were at the 0.05 level of probability. Effects of season were not evaluated statistically.

RESULTS AND DISCUSSION

Girdling and chemically treating shoots in late July strikingly improved rooting and reduced losses to needle senescence (Experiment 1, table 1). This

Table 1.--Effect of girdling on rooting and senescence of cuttings from 12-year-old slash pine

Experiment No.	Time in propagation bed	Rooted		Senescent and dead	
		Girdled and pretreated	Control	Girdled and pretreated	Control
	Months	Percent			
1[a/]	1	15.6*	0	1.2*	25.0
	2	26.9*	1.2	11.9*	74.4
	3	33.8*	1.2	34.4*	93.0
2[b/]	3	3.1	0.5	88.5	95.8

a/ Girdled July 30, taken Sep. 30.
b/ Girdled Oct. 24, taken Dec. 24.
*Girdled and control pair differs at the 0.05 level.

senescence starts as a yellowing of needle bases, progresses to browning of needles, and eventually kills the cutting. In Experiment 1, most of the ungirdled cuttings were dead or dying from needle-base senescence within 3 months, and only 1 percent had rooted. In contrast, 66 percent of the girdled cuttings were still healthy, and half of these had rooted. Microorganisms were not involved initially in the senescence syndrome, as the stem and distal portions of foliage were sound and healthy. Presumably, the dead tissue prevents movement of photosynthates, causing the stem to starve. Where carbohydrate reserves had been increased by girdling, premature senescence was not a serious problem.

In contrast to the July treatment, girdling in late October did not significantly promote rooting or reduce needle senescence (Experiment 2, table 1). Apparently, photosynthesis was too low during November and December to accumulate sufficient reserves above the girdle. Possibly more time between girdle and take would help in winter. Another deterring factor may have been low light intensity in the greenhouse. In a growth chamber, where photosynthesis was high, ungirdled cuttings from a December take rooted well (Hare 1974).

These seasonal differences in response to girdling are to be expected. Production and utilization of food reserves are controlled directly by season through light and temperature effects on photosynthesis and respiration. Season also indirectly affects reserve utilization through the presence of actively growing vegetative or floral sinks. Thus, the most effective season for girdling should be when light and temperature are near optimum, i.e., bright days and cool nights, and when active growth is limited, perhaps late summer.

In both these experiments, bed effects were negligible. This consistency of response between greenhouses lends credibility to the results and suggests that the rooting technique could be implemented on a large scale with confidence.

One minor problem was encountered in Experiment 1. Although girdling *per se* almost never killed the shoot, it did weaken the stem so that about 17 percent of the shoots were broken off, apparently in strong winds. Breakage did not occur in Experiment 2.

In Experiment 1, 97 percent of the girdled cuttings had callus after 3 months in the propagation bed compared to only 9 percent of the ungirdled. At time of taking, 13 percent of the girdled cuttings showed obvious root initials, which appeared as protuberances on the callus. All such cuttings rooted within 2 months, and most had large root systems with up to 30 main roots in just 1 month. Cuttings from older pines usually produce only a few roots and may not survive after planting (Boeijink and van Broekhuizen 1974). Therefore, the large root systems obtained from cuttings showing preformed initials may be important. Perhaps with more time between girdle and take, a higher percentage of this type of cutting could be produced during favorable seasons. One possible application involves girdling perhaps 10 times as many shoots as needed and then processing only those showing root initials. Valuable greenhouse space would be conserved, and propagating beds would be in use for only 1 or 2 months between takes.

Girdling, combined with application of a paste containing indolebutyric acid in talc, is now a standard pre-severance treatment on older radiata pine trees in New Zealand (Cameron and Rook 1974). It now appears that girdling plus chemical treatment should also be used, at the proper season, for rooting southern pines.

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APPENDIX

FORMULA FOR 1-1-10-10-1 ROOTING POWDER

Dissolve 1.0 gm IBA (indolebutyric acid), 1.0 gm PPZ (1-phenyl-3-methyl-5-pyrazolone, K & K Laboratories, Plainview, N.Y.[2/]), and 1.1 gm Alar-90 (90% B-Nine, Naugatuck Chemical Co., Naugatuck, Conn.) in 70 ml anhydrous acetone; the Alar will not dissolve completely. Transfer quantitatively to 67 gm talc (Baker USP) in a bowl. Stir slurry constantly in a hood over gentle heat and under a gentle air stream until completely dry. Sift through a stack of sieves, to 60 mesh. Mix well with 20 gm sifted captan 50W (Orthocide 50) and 10 gm dried and sifted 10X confectionery sugar. Grind the final mixture in a large mortar and sift again.

[2/] Mention of trade names and suppliers is solely to identify materials used and does not imply endorsement by the U. S. Department of Agriculture.

GROWTH OF LOBLOLLY SCION MATERIAL ON ROOTSTOCKS OF KNOWN GENETIC ORIGIN

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Abstract.--Scion material was collected from compatible and incompatible loblolly ramets and grafted onto known families of loblolly and slash pine. Early evaluation of scion growth indicated significant differences between the two clones used as a source of scions. No difference was observed between rootstock species, although families within rootstock species did show to influence the growth of the scion material. Graft survival was 93.1 percent and was not statistically analyzed.

Additional keywords: Grafting, graft development, vegetative propagation, Pinus elliottii, P. taeda.

Studies involving forest species have indicated that scion growth and performance may be influenced by the type of rootstock used. Allen (1967) reported that loblolly pine (Pinus taeda L.) rootstock increased growth of shortleaf pine (Pinus echinata Mill.) scion material in comparison to shortleaf rootstock. The number of graft failures was also lower in the shortleaf-loblolly combination. In a study involving different species as rootstocks and scions, Ahlgren (1972) observed that white pine (Pinus strobus L.) rootstocks were frequently associated with rapid scion growth while red pine (Pinus resinosa Ait.) rootstocks demonstrated the opposite effect. Different species of rootstocks have also shown to affect the flowering behavior of the scion (Schmidtling 1973).

In order to further evaluate the influence of rootstock upon scion development, this study was established using genetically identified sources of loblolly and slash pine (Pinus elliottii Engelm.) as rootstocks.

METHODS AND MATERIALS

To provide genetically identified rootstock, seeds from four families of loblolly pine and two families of slash pine were collected from orchard ramets. Both open-pollinated and control-pollinated families were selected. Planting was done at the Indian Mound Nursery near Alto, Texas in May, 1972, and the seedlings were allowed to grow for one year under normal nursery conditions.

In March, 1973 scions were collected from two different clones in a 10-year old loblolly scion bank. These two clones were selected solely on the basis of their having incompatible ramets from which to collect scion material. Cuttings were obtained from both a compatible ramet and an incompatible ramet for each of the selected clones, with incompatible ramets identified by a stunted, chlorotic appearance. Neither incompatible ramet exhibited signs of

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severe union deformation, although one did show a slight swelling immediately above the union.

Following collection, cuttings were put into plastic bags and placed on ice for transporting to the nursery. A side graft was used, similar to the procedure described by Webb (1961). Completed grafts were covered by a polyethylene bag, with a small amount of commercial insecticide dusted inside each bag to control insects. Bags were subsequently removed following development of "pin-feather" needles on the scion, or upon death of the scion. The rootstock was later pruned to allow the scion to attain dominance.

A total of 290 grafts were made with 130 being made on loblolly rootstock and 160 on slash rootstock. Length of the scion was measured at the time of grafting to allow for a later determination of growth. An evaluation of graft survival and measurements of scion growth were made on July 15, 1973.

RESULTS

Only 20 of the 290 grafts died prior to July 15, 1973. Nine of the dead grafts were on loblolly rootstock, and 11 were on slash rootstock. Because of the small number of dead grafts, no statistical analysis was performed.

Average scion growth for the various graft combinations was obtained. A summary of this data for each of the main effects is given in Table 1. Analysis was performed using the least-squares regression method of the Statistical Analysis System (Barr and Goodnight 1972), and is presented in Table 2. Statistical significance was observed for differences between scion clones, between compatible and incompatible ramets, and among families within species. Differences between rootstock species and for various interactions were not observed.

Table 1--Average scion growth (cm.) for main effects of clonal scion material grafted onto known rootstock

Main Effect	Classification	Average Scion Growth (cm.)
Scion clone	D3PT10	16.2
	D3PT16	12.7
Ramet compatibility of scion clone	Compatible	16.4
	Incompatible	11.8
Rootstock species	Loblolly	14.7
	Slash	13.9
Source within species (loblolly)	6-44 x Open	17.6
	4-14 x 10-2	13.6
	10-2 x W	13.4
	5-6 x 15-10	12.7
(slash)	D12PC29 x Open	14.3
	D12PC93 x Open	13.5

Table 2--Analysis of variance for scion growth of clonal scion material grafted onto known rootstock

Source	d.f.	S.S.	M.S.	F Value
Scion clone (Scl)	1	807.48	807.48	20.05**
Ramet compatibility (Comp)	1	1310.32	1310.32	32.54**
Rootstock species (Rs)	1	103.27	103.27	2.56
Source within rootstock species (S)	4	397.09	99.27	2.47*
Scl x Comp	1	.24	.24	.01
Scl x Rs	1	4.53	4.53	.11
Scl x S	3[1/]	198.36	66.12	1.64
Comp x Rs	1	67.94	67.94	1.69
Comp x S	4	236.76	59.19	1.47
Error	247	9943.57	40.26	
Total	264[2/]	13069.56		

* Denotes significance at .05 level of probability
** Denotes significance at .01 level of probability.

[1/] Scion clone D3PT10 was not grafted onto loblolly source 5-6 x 15-10.
[2/] Five grafts could not be measured due to a broken terminal bud.

DISCUSSION

Excellent graft survival was observed approximately four months after grafting. This response is attributed to the use of previously grafted material as scions, grafting by experienced personnel, and proper aftercare. Because grafts continue to die throughout the first growing season, no conclusions could be made.

The observation that scion clone D3PT10 produced significantly more growth than did clone D3PT16 suggests that clonal differences for scion growth may be expressed early in the life of the graft. Field observation of the two clones in the scion bank indicated that any initial differences in growth had disappeared after 10 years, which is most likely due to a moderating effect of intense orchard management.

Scions collected from compatible ramets performed better than did material collected from incompatible ramets. Since the cuttings are genetically identical for each clone, this response is assumed to be the result of decreased vigor in incompatible ramets. Other mechanisms such as infectious viruses or toxic compounds associated with the rootstock of the original ramet cannot be eliminated on the basis of this study, and thus should be considered as possible contributing factors.

Although no difference was observed between the two species used as rootstock, families within species demonstrated a significant effect with loblolly source 6-44 x open resulting in the most scion growth. Determination of whether or not this difference persists over a period of time would require future evaluation, however the important point is that rootstock genotype did influence the growth of the scion material during the first growing season after grafting. Such a response indicates a definite need to select a satisfactory rootstock source prior to the initiation of a grafting program.

The effect of different rootstock families implies that by establishing breeding programs for specific genotypes to be used as rootstock, it may be possible to more precisely control graft development. In addition, such problems as graft incompatibility may also be overcome.

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GENETIC CONTROL OF DRY MATTER DISTRIBUTION IN TWENTY HALF-SIB FAMILIES OF VIRGINIA PINE

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Abstract.--Half-sib progeny derived from 20 Pinus virginiana parent trees were sampled, at age eight, to determine presence of significant among family differences in the distribution of dry matter. Families differed in branch weight but not in stem wood, stem bark, leaf, or total wood weight. Proportionate distributions of dry weights for stem, wood branch and stem bark were significantly different among the 20 families. Differences in proportionate distributions were independent of tree size. Heritability (h^2) estimates were high for the stem weight and wood weight proportion of dry weight but only moderate for height, diameter and branch weight.

Additional keywords: Biomass, Pinus virginiana, dry matter distribution.

INTRODUCTION

In Virginia, Virginia pine (Pinus virginiana Mill.) accounts for approximately 28% of the softwood growing stock (Sternitzke and Nelson, 1970) and about 44% of the total softwood acreage (Knight and McClure, 1967). Because Virginia pine can provide high per acre yields, has a rapid juvenile growth, and is easily regenerated, industries and state forestry groups in several southern states have incorporated Virginia pine into their procurement, planting and breeding programs (Thor, 1964).

Genetic improvement of Virginia pine requires basic knowledge of the genetic control of tree characteristics important for growth and yield improvement. Because yield of stemwood remains the single most important factor in measuring the results of tree improvement efforts, an understanding of the genetics of dry matter distribution is important if efficient selection methods are to be chosen for breeding improved trees. This study was designed to investigate the genetic control of dry matter production and distribution in twenty Virginia pine half-sib families at age eight years.

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LITERATURE REVIEW

A number of dry matter production studies have dealt with the distribution of dry matter in stands. These studies have been carried out for a variety of reasons, including investigations of the differences between stands growing under different stocking density (Johnstone, 1971) and investigations of the effect of age (Forrest and Ovington, 1970; Hegyi, 1972). Studies have been conducted to provide information for tree nutrition studies (Ovington and Madgwick, 1959; Keay and Turton, 1970; Forrest and Ovington, 1971) and to provide information on differences caused by fertilization (Keay and Turton, 1970).

Satoo (1966) states that in some cases significant variation in the distribution of dry matter has been found among dominant trees in a stand. If this variation in distribution is shown to be genetically controlled, it may be possible to increase the timber yield (stem-wood), even where no increase in total dry matter production occurs. No studies have dealt directly with genetic differences in dry matter distribution among families of plantation-grown Virginia pine.

MATERIALS AND METHODS

In the fall of 1963 Bramlett (1965) collected cones from 20 selected Virginia pine trees. The trees were selected in pairs of naturally well- and poorly-pruned trees and each pair was similar in age, height, diameter, and surrounding stand density. After extraction, seed was sown on May 5, 1964 in nursery beds on the Lee Experimental Forest in Buckingham County, Virginia and outplanted in two randomized blocks in March, 1965. Each family was represented in each block by one 3-tree by 5-tree plot with all seedlings planted at an 8 x 8 foot spacing (Bramlett, 1965).

Five trees from each family in each block were used as the sample for this study. Every third tree in each row in the stand was cut at ground level. One hundred eighty two sample trees were cut during the winter of 1972; 10 from each of the 20 families, less 18 dead and missing trees.

The following measurements were made on each sample tree:

1. Diameter at 1.35 meters (DBH) to the nearest mm.
2. Total height to the nearest cm.
3. Total live crown fresh weight at time of felling.
4. The fresh weight of a random subsample of the crown, representing approximately 10% of the live crown.
5. The total dry weight of stem bark and stem wood.
6. The dry weight of needles and branches in the subsample.

Weights were taken to the nearest 0.1 gram for all samples except stem-wood, which was weighed to the nearest 14 g.

At the time of sampling, crown closure within the stand had just begun and loss of branch material due to natural pruning was negligible. It was

assumed that branch weight, stem wood-weight, and stem bark-weight represented the total amount of dry matter (called total wood-weight) distributed to these three parts of the tree over the 8 years of the stand's existence. Leaf weight represented current production only.

Analyses of variance were used to test for differences among the 20 families in diameter, height, the absolute amount of branch, leaf, stem, stem bark, and total wood-weight and for differences in proportionate distribution of woody material.

Heritability (h^2) estimates to determine the relative amount of genetic control over the measured parameters and the distribution of dry matter among the woody components were calculated as follows:

$$\frac{4\delta^2 F}{\delta^2 F + \delta^2 W}$$

where: $\delta^2 F$ = variance due to mother tree (1/2 sib family)
$\delta^2 W$ = variance within families (Becker, 1964)

RESULTS

Variation In Tree Dimensions and Component By Weight

The sampled trees varied in size; the largest tree of each family was 1.5 to 2.0 times as large as the smallest tree in stem diameter (DBH) and height. The range of values for tree diameter and height within families was greater than between family averages. Analysis of variance was performed for branch weight, leaf weight, stem wood-weight, stem bark-weight, and the total wood-weight and results are presented in Table 1. Differences between families in branch weight were significant and varied by a factor of 2 (Table 2). Differences among family averages for leaf weight, stem wood-weight, and stem bark-weight (Table 2) were not significant at P = 0.05 (Table 1).

Table 1: Analyses of variance for height, diameter, leaf weight, cone weight, weight of woody components, and total wood-weight for 20 families of Virginia pine.

Variable	Source of Variance	df, Error df	Mean Square	F. Value	Probability Of Larger F
Height (m)	Family	19 162	0.578	1.790	0.0275
Diameter (cm)	Family	19 162	3.127	1.678	0.0445
Leaf Wt. (kg)	Family	19 162	1.360	1.41	0.1293
Branch Wt. (kg)	Family	19 162	11.05	1.78	0.0285
Stem Wt. (kg)	Family	19 162	3.640	1.33	0.1698
Bark Wt. (kg)	Family	19 162	0.122	1.57	0.0682
Wood Wt. (kg)	Family	19 162	25.60	1.42	0.1242

Table 2: Family averages for tree measurements and weight of component parts. All weights in Kilograms, height in meters and diameters in centimeters. Means not followed by the same letter are significantly different at P = 0.05.

Family	Ht (M)	Dia (cm)	Branch	Leaf	Stem	Bark
			KILOGRAMS			
1	4.33abcd	7.3abc	6.75ab	2.93	4.95	0.92
2	4.18bcd	6.0cd	3.97c	2.12	3.32	0.64
3	4.12cd	6.3abcd	6.21abc	2.41	3.52	0.73
4	4.74abc	7.5ab	5.74abc	2.66	5.08	1.04
5	4.49abcd	7.2abc	6.15abc	2.85	4.79	0.91
6	4.81abc	6.8abcd	5.05bc	2.39	4.55	0.87
21	4.61abc	7.4abc	8.39a	3.35	4.89	1.06
22	4.83a	7.3abc	6.40abc	2.44	5.18	0.91
23	3.97d	5.7d	3.93c	1.79	3.06	0.68
24	4.21abcd	6.1bcd	5.99abc	2.07	4.10	0.79
25	4.63abc	6.9abcd	6.99ab	2.98	4.63	0.92
26	4.81ab	7.0abcd	6.05abc	2.47	4.87	0.90
37	4.37abcd	6.5abcd	6.61abc	2.71	4.53	0.85
38	4.21abcd	6.3abcd	7.53ab	2.55	4.00	0.82
41	4.35abcd	6.8abcd	6.21abc	2.61	4.25	0.94
42	4.51abcd	7.8a	7.07ab	2.86	5.08	1.01
45	4.21abcd	6.7abcd	6.47abc	3.17	4.15	0.79
46	4.55abcd	7.3abc	7.29ab	2.88	4.87	0.97
47	4.51abcd	7.0abcd	6.60abc	2.59	4.38	0.94
48	4.23abcd	6.3abcd	5.18bc	2.43	3.72	0.78
MEAN	4.43	6.8	6.20	2.61	4.40	0.87
Std. Dev. of the mean	0.59	1.4	2.59	1.00	1.68	0.29

Variation In Dry Matter Distribution

The proportionate distribution of dry matter among the woody components was expressed as the percent of the total wood-weight. There were significant differences among families in the dry matter distribution among the three woody components (Table 3). In each family, branch weight was larger than stem wood-weight, and in all but four families (2, 4, 6, and 23), branch weight was greater than the total of stem wood-weight and stem bark-weight combined (Table 4).

The sample trees were divided into 1 cm diameter classes (i.e. 3.5 to 4.4, 4.5 to 5.4, etc.). Proportionate distribution of woody material into branches and stem was shown to be non-significant among the diameter classes (P = .50 and .18, respectfully). However, proportionate distribution to bark weight was significantly different among the diameter classes (P = .01).

Table 3: Analyses of variance for the proportionate distribution of dry matter among the woody components in 20 families of Virginia pine.

Variable	Source of Variance	df, error df	Mean Square	F. Value	Prob. of Larger F
BR/Wood[1)]	Family	19 162	115.004	4.967	0.0001
ST/Wood[2)]	Family	19 162	85.828	4.928	0.0001
BK/Wood[3)]	Family	19 162	3.962	1.731	0.0356

1) BR/Wood = (Branch weight/Wood weight) X 100.
2) ST/Wood = (Stem weight/Wood weight) X 100.
3) BK/Wood = (Bark weight/Wood weight) X 100.

Table 4: Family averages for total wood weight (kg) and proportionate distribution of woody material into branch, stem, and stem bark. Means not followed by the same letter are significantly different at P = 0.05.

Family	Total Wood Wt.	% Branch	% Stem	% Bark
1	12.62	53.5cdef	39.2abcdef	7.3abc
2	7.93	50.1efg	41.8abc	8.1abc
3	10.46	59.4ab	33.7g	6.9c
4	11.86	48.4fg	42.8ab	8.8ab
5	11.86	51.9cdefg	40.4abcdef	7.7abc
6	10.47	48.2g	43.4a	8.3abc
21	14.34	58.5ab	34.1g	7.4bc
22	12.49	51.2cdefg	41.5abcd	7.3bc
23	7.67	51.3defg	39.9abcdef	8.8a
24	10.88	55.1cdef	37.7bcdef	7.2abc
25	12.54	55.8abcd	36.9cdef	7.3bc
26	11.82	51.2cdefg	41.2abcde	7.6abc
37	11.99	55.1abc	37.8fg	7.1bc
38	12.35	61.0a	32.3g	6.7c
41	11.39	54.5bcde	37.3cdefg	8.2abc
42	13.16	53.7cdef	38.6bcdef	7.7abc
45	11.41	56.7abc	36.3efg	6.9c
46	13.13	55.5abc	37.1defg	7.4bc
47	11.38	53.2cdef	38.5bcdef	8.3abc
48	9.68	53.5cdef	38.4cdef	8.1abc
MEAN	11.47	54.1	38.3	7.6
Std. Dev. of the Mean	4.34	5.7	4.9	1.6

Heritability Estimates

Heritability (h^2) estimates were calculated for those values which showed significant among family differences (Table 5). Height, diameter, and branch weight had moderate heritability values. Heritability estimates for proportionate distribution of dry matter among the three woody components varied from 0.30 to 1.21. Theoretically, heritability values greater than 1.00 (Table 5) are not possible but may be obtained if assumptions of heritability calculations are not met. One assumption which must be met is that the selection of parent trees be completely random (Falconer, 1960). For this study, the parent trees were not selected at random, since the selection was based on the natural self-pruning ability of each parent tree. Consequently, the selection procedure may have caused biased estimates of heritability especially for the proportionate distribution of woody material since naturally poorly-pruned trees have thicker and longer branches than naturally well-pruned trees (Bailey, 1974).

Table 5: Esimtates of heritabilities (h^2) for measured parameters and distribution of dry matter among the woody components.

Variable	h^2
Height	.32
Diameter	.28
Branch Wt.	.32
Branch Wt./Wood-Wt.	1.21*
Stem Wt./Wood-Wt.	1.21*
Bark Wt./Wood-Wt.	.30

*See text for explanation.

Sampled trees were classified into two groups, those from naturally poorly-pruned parents or from well-pruned parents. Analysis of variance showed that the progeny from poorly-pruned parents had a significantly (P = .006) higher percentage of woody material in branch weight. Conversely, progeny from well-pruned parents had a significantly (P = .003) higher proportion of total woody material in the stem. The two progeny groups did not differ significantly in the ratio of bark weight to total wood-weight nor did they differ significantly in total wood-weight.

DISCUSSION

The results of this study indicate that total wood mass in the eight-year-old Virginia pine population studied here is subject to only minor genetic influence. Consequently, improvement of total woody biomass productivity of this Virginia pine population will be relatively slow. The results do suggest that improvement can be made in the proportionate distribution of dry matter to

the stem. For example, if the total average wood productivity of the trees in the stand could be genetically manipulated so that proportionate distribution of dry matter to the stem was as great as in family 6, the yield of dry stem would increase approximately 13%. If the family with the greatest total wood productivity (Family 21) could be manipulated such that it produced a percent stem wood comparable to family 6, productivity of stem wood would be 30% greater than the plantation average.

Resampling the families included in this study at varying intervals to maturity will provide needed information on the temporal stability of characters measured in this study, on the variations in foliage efficiency, and more reliable estimates of heritability. Knowledge of the genetics of biomass distribution may increase understanding of the mechanisms responsible for individual tree productivity and through such an understanding, contribute to the efficiency of tree breeding programs.

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FROM PROGENY TESTING TO SEED ORCHARD THROUGH MATHEMATICAL PROGRAMMING

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Abstract.--Ideal seed orchards have balanced, maximized genetic gain on all favorable traits, produce a maximum number of seed at the earliest age, enjoy the greatest longevity, have minimum costs for establishment and maintenance, and have minimum risk of failure. The conflicting objectives of such an orchard, as well as the many associated restraints and interactions, obviously call for many compromises. Mathematical programming seems to be a logical approach to maximizing gain in this complex problem. A hypothetical case study, using black walnut, is outlined.

Additional keywords: Operations research, breeding value, optimization

HISTORY AND DEVELOPMENT OF OPERATIONS RESEARCH

During World War II, a team of British scientists was called together to study the strategic and tactical problems associated with the defense of England. Because the team was working with research on military operations, they coined the term "Operations Research". The team was concerned with developing the "best" defense system with the resources available. Encouraging results achieved by the British team motivated the United States to try similar military management programs.

After the war, word began to leak out about the accomplishments of operations research. Industrial and business managers began using the new tool in quantitative decision making. Soon the applications of operations research, or the management sciences, spread into many fields and organizations.

Operations research in forestry has been concerned with problems involving forest-produced goods and services. About 400 papers have been published between 1960 and 1970 on this subject (Martin and Sendak 1973). In forest tree improvement Buijtenen and Saitta (1973) applied linear programming to the economic analysis of seed orchard operations. Porterfield (1974) used goal programming to seek a combination of traits to be selected and define the optimum intensity of selection for each trait. In this paper we will try to illustrate the feasibilities of utilizing mathematical programming in a genetic reproduction system.

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OUTLOOK FOR BIOLOGICAL SYSTEMS MANAGEMENT SCIENCE

The advancement of population biology has followed the development of mathematical theory. During the period 1920 to 1940, Fisher, Lush, and Wright developed quantitative genetics through mathematical statistics. Using their work as a basis, many population studies were made. From network and control system technology developed by electrical engineers during the 40's and 50's, we now have systematic ecology. We believe that in the next few years, operations research will be commonly applied to biology and a new discipline of biological systems management science will emerge.

Cost, volume, profit analysis can be used for population behavior study. Game theory can be used to analyze biological interrelations. Transportation problems and network models are valuable in simulating food chains. In forest tree improvement programs, the product mix model may offer the best approach for seed orchard establishment and management.

Seed orchards may have several objectives. One consumer (tree grower) may want maximum growth rate, while another desires seed production, winter hardiness, or frost avoidance. The ideal seed orchard would have balanced, maximized genetic gain on all favorable traits, produce a maximum number of seed at the earliest age, enjoy the greatest longevity, have minimum costs for establishment and maintenance, and have minimum risk of failure.

The conflicting objectives of such an orchard, as well as the many associated restraints and interactions, obviously call for many compromises. Genetic correlation among traits, balance between vegetative growth and reproduction, timing of flowering among selected trees, and associated costs for each expected genetic gain must all be considered. Mathematical programming seems to be a logical approach to maximizing gain in this complex problem.

A HYPOTHETICAL EXAMPLE

For our example, we will use black walnut and consider progeny tests followed by establishment of grafted elite orchards (Gustafsson 1949). Such an approach offers flexibility in seed orchard design, maximum use of land, opportunity for expansion of the orchard with the need for additional seed, and greater genetic gain (Wright 1964, Stern and Hattemer 1964). The grafted elite orchard approach is more expensive and requires a longer wait for improved seed than for orchards developed by thinning test plantations.

In planning a black walnut seed orchard, we will assume it will begin with a half-sib progeny test. Mother trees are randomly selected from their native range. The performance of the offspring of the best three wind pollinated mother trees and the commercial stock (assumed to be equal to the average performance in the test plantation) are listed as follows:

Mother tree	Trait: Volume produced at age 50 (Bd.ft.)	Nut meat quality (Grade)	Annual nut yield (No.)	Cost per seed tree ($)
"Wood"	437.5	5.0	1050	7
"Meat"	427.5	7.5	1010	8
"Nut"	387.5	6.5	1100	9
Commercial stock	375.0	5.0	1000	8

The mother tree "Wood" is for superior wood production, "Meat" is for the best kernel quality, and "Nut" is for the greatest number of seed yield. The cost per seed tree included the present values of grafting, land and other maintenance costs.

The breeding value for the three mother trees can be computed from the formula $Xij = 1/2(BVij + Ave.)$ or $BVij = 2Xij - Ave.$

where Xij is the performance of half-sib family i for trait j.

BVij is the breeding value of the mother tree i for trait j.

Ave. is the mean of the population, or the breeding value of a random-sampled, wind-born pollen.

The results are as follows:

Mother tree	Breeding value for trait: Volume produced at age 50 (Bd.ft.)	Nut meat quality (Grade)	Annual nut yield (No.)	Cost per seed tree ($)
"Wood"	500	5	1100	7
"Meat"	480	10	1020	8
"Nut"	400	8	1200	9

Let us assume that a seed orchard is to be established from grafts of these three mother trees. Furthermore, the three criteria, volume of board feet produced, meat quality, and nut production, are assumed to be additive. The following additional typical conditions are assumed:

1. At least 50 ramets in any variety should be present in the seed orchard.

2. On the average, offspring from this seed orchard should yield at least 20% more lumber and nuts than the commercial stock (i.e., seed from the average mother tree).

3. On the average, offspring from this seed orchard should yield a grade 6 or better for meat quality.

4. The total cost for the seed orchard should be less than or equal to $10,080.

5. The objective is to maximize annual seed yield from the seed orchard.

The questions are: (1) How many trees in each variety should be planted? (2) What are the estimated potential yields for board feet of volume produced, meat quality and annual nut production from the genetically improved seed? and (3) How many improved seed will be available annually from the elite orchard?

In order to solve the problem, the problem was first formulated as follows:

Maximizing $1100X_1 + 1020X_2 + 1200X_3$.

Subject to $X_1, X_2, X_3 > 50$

$$500X_1 + 480X_2 + 400X_3 \geqslant 375(1 + .2)(X_1 + X_2 + X_3)$$

$$1100X_1 + 1020X_2 + 1200X_3 \geqslant 1000(1 + .2)(X_1 + X_2 + X_3)$$

$$5X_1 + 10X_2 + 8X_3 \geqslant 6(X_1 + X_2 + X_3)$$

$$7X_1 + 8X_2 + 9X_3 \leqslant 10080$$

where X_1, X_2 and X_3 are the number of clones from "Wood", "Meat", and "Nut" respectively.

The problem was solved by means of the criss-cross method (Zionts 1969). The optimal solutions for questions 1 and 3 are as follows:

Clone name	Ramets needed (No.)	Seed yield expected
"Wood"	1092	1,195,000
"Meat"	248	262,000
"Nut"	50	57,000
Total	1390	1,514,000

The potential performance from the genetically improved seed can be computed as the weighted mean of clonal performances. For example, the potential yield for volume for the average seed would be as follows:

$$\frac{1092(500) + 248(480) + 50(400)}{1092 + 248 + 50} = 493$$

We can also estimate the performance of the seed from a particular clone. Assuming random mating and additive gene action, the seedlings from clone "Wood" have the potential to grow to (500 + 493)/2 = 496.5 bd. ft. at age 50. The performances of seedlings from three clones for three traits are listed in the following table:

Clone name	Performance: Volume produced at age 50 (Bd.ft.)	Meat quality (Grade)	Annual nut yield (No.)
"Wood"	496.5	5.5	1095
"Meat"	486.5	8.0	1055
"Nut"	446.5	7.0	1145
Average	493	6.0	1090

By keeping seed from each clone separate, multiple objective and custom seed orders for multiple objectives can become a reality (Bey and Kung 1973). For example, if a customer's specifications for seed are as follows:

1. The average volume per tree produced at age 50 should equal or be greater than 480 bd. ft.

2. The average meat quality should equal or exceed grade 7.

The seed orchard manager can fill the order by:

1. all seed drawn from "Meat".

2. 40% of seed from "Wood" and 60% from "Meat".

3. 16% of seed from "Nut" and 84% from "Meat".

The problem of satisfying many customers when each one has a special order may seem complex and difficult. However, the problem can be formulated as "Product Mix Model" and solved by computer in just a few seconds. The record keeping could be quite simple for the orchard manager and nurseryman. Orchard trees selected for rapid growth might be painted red, those selected for nut meat quality white, and those for nut production blue. Seed from each color group would then be kept separate for later planting in the nursery or for shipping seed directly to the customer.

CASE STUDY PROPOSAL

Before the system is in operation, we need to (1) build models, (2) modify models, (3) test models, and (4) develop plans for seed orchard establishment. The development of each phase is very dependent on the previous phase. Some of the important considerations in development are listed below:

I. Model Building

A. Biological, economical and managerial restraints will be identified and assessed.

1. Geographic seed source studies will provide information on adaptability for various traits.

2. Progeny tests will provide information on breeding value of selected trees. Growth, cold hardiness, phenology, form, drought hardiness, seed production, and insect and disease resistance will be evaluated. Heritability and genetic correlation among traits will be obtained.

3. Twin walnut progeny tests will be used to assess variance components.

4. Feasibility of grafting and rooting walnut will be evaluated.

5. Genotype x environment interaction will be evaluated. Effects of wind, irrigation, and cover crops will be included.

6. Economic and managerial restraint information will be developed from field experience of orchard managers.

B. Setting objective functions.--When we maximize gain for a single objective, we automatically reduce gain for another. It therefore becomes necessary to set objective priorities. In addition to ranking the various traits that we want to select for, we need to consider the time it takes to obtain the objective, how many years it will continue, and an estimate of the risk involved.

C. Assessing genetic worth of individual trees.--Whether an individual tree remains in a gene pool depends in part on its breeding value for each of the traits evaluated. The costs and benefits associated with including (or excluding) each candidate in the seed orchard will be determined and incorporated into the various models for testing.

II. Model modification. As new developments occur, it will be necessary to modify the model. The following changes will make it necessary to modify the models:

A. As new biological, economical, and managerial information becomes available, restraints will have to be added or deleted accordingly.

B. As socio-economic behaviors change (such as customer's needs), objective functions will have to be changed.

C. As the techniques in operations research-management sciences are improved, they will be applied to the model building and testing process.

C. Wherever possible, where change can be predicted, it will be incorporated in the model as a dynamic function.

III. Model testing. Based on models that have been built, we plan to establish second generation walnut orchards. Data from trees in these orchards will be compared with expected results from models developed.

IV. Putting the models to work. After the models have been built and verified, recommendations for establishing black walnut seed orchards will be made. The types of trees to include in the orchard, spacing, design, intensity of selection, traits to select for, etc., will be included in the recommendations.

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